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Dr. Jim Romano and Nancy Steen

I have created these study notes to help you study for the DAT. I created the DAT Destroyer book with marketing executive and co/owner Nancy Steen in 2006. The Destroyer book has been used by thousands of students each year and is updated yearly to reflect all new trends on your exam. These study notes were born out of necessity. “Study notes” available made by students who plagiarized Campbell text, Barron’s, Cliffs, Destroyer, and Wiki are simply a waste of time. My notes reflect the work I use with my students. Not a week goes by that I don’t hear from students who were led to believe that using a “study guide” or “notes” were the secret formula. You need to work hard, and stay focused. These notes are on target for the DAT and OAT exam, and will build a great foundation even for the MCAT. Our DAT Destroyer Study Group on Facebook was created in late 2017, and I invite you all to join. I post many questions daily. The range of questions are from Biology, Chemistry, Histology, Anatomy, Physiology, Genetics, Immunology, Pathology, and more. I personally spearhead and lead this group.

How do you use these notes?

I would do a chapter a day before you pick up the DAT Destroyer. You need to build a solid foundation and base. Knowing all these notes will make the Destroyer manageable. Don’t be scammed by companies and bloviators who tell you not to do all the problems. You need to do every problem in my book. These Bio notes are now your notes. Add to them, add additional comments to them, make them your masterpiece. I have laid down a solid foundation for you.

I also have a Chemistry guideline that will tell you where to focus. This is also essential for you to see.

Our Facebook study group has many free Chemistry videos. Don’t waste your money on chemistry videos. I will release an arsenal to you all for free. If you are stuck, the Khan Academy videos are free as well. I am always available to answer a question, and if needed professors, at my institute can be available for a Skype lecture. There is no single path on how to study. Do not be fooled or conned to believe that a study guide is all you need. Build your foundation and work your butt off!

For General Chemistry, the Raymond Chang text and my General Chemistry Destroyer will show you any conceivable problem they can ask. For Organic Chemistry, the David Klein text and Organic Odyssey will easily be your path to a 30.

I hope these notes will be a huge asset to your study tools. In addition, for the PAT, my students all use Crack the DAT and for the math... the Math Destroyer.

I wish you all good luck on this journey and I look forward to meeting you in the Facebook study group!

I dedicate these notes to my best friend Millie who taught me the meaning of strength and courage.

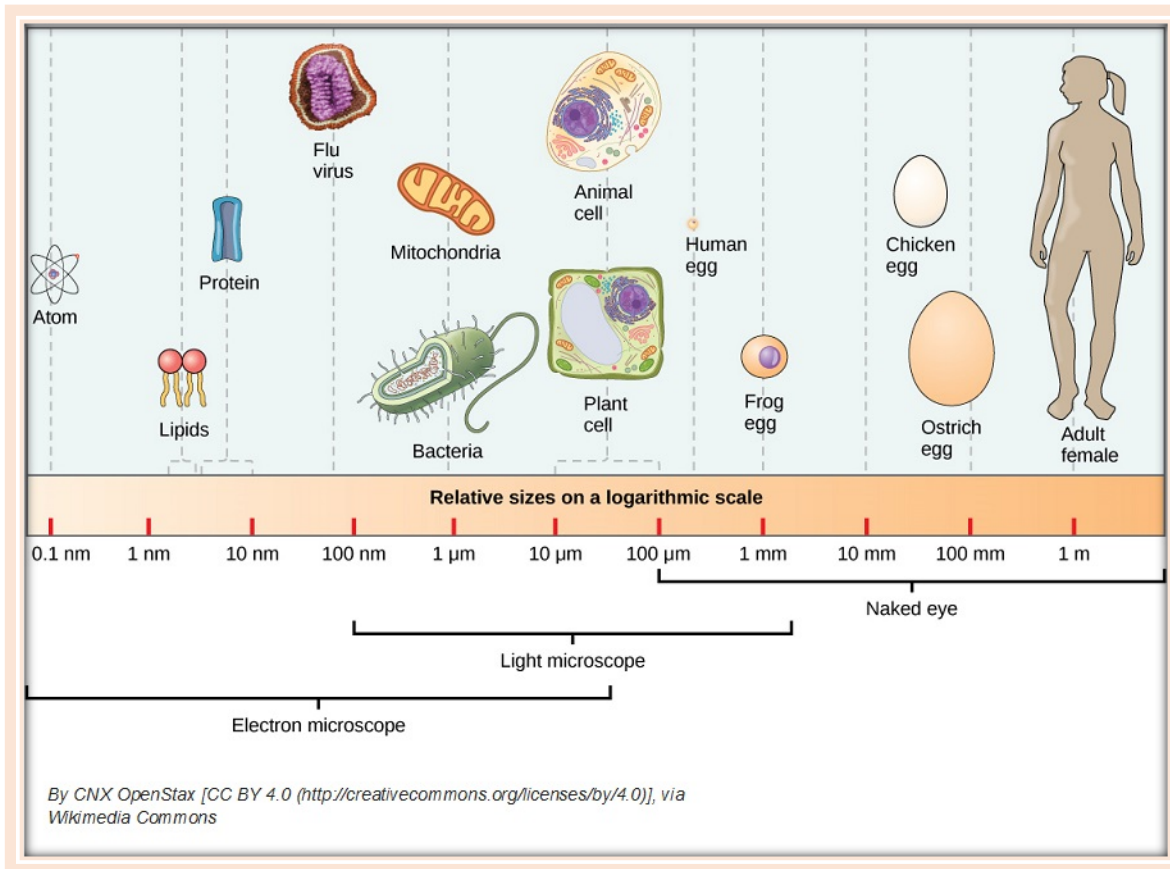
A handwritten signature in black ink, appearing to read "Dr. Jonathan". The signature is fluid and cursive, with a large loop for the 'D' and a long, sweeping underline.

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Chapter 1 - Biological Concept Introduction

Biological Concept Introduction



Biology is the study of living things. All living organisms must have some degree of order. Living things must be able to take energy from the environment and use that energy to maintain orderliness for their own bodies to grow and reproduce.

An **atom** is the smallest unit of an element that retains all the properties of the element. Two or more atoms chemically linked is called a **molecule**.

Elements include Sb, Te, B, Au, Ag. They cannot be broken down into other substances.

A molecule and a compound are words usually interchanged in biology, thus we need not get into semantics.

Matter is anything that occupies space and has mass. As of November 2017, 118 known elements reside on the Periodic Table. In biology, C, H, N, O, P, S are the main players. Elements that are vital such as Mo, Zn, or Cu are present in small amounts and we sometimes call them trace elements.

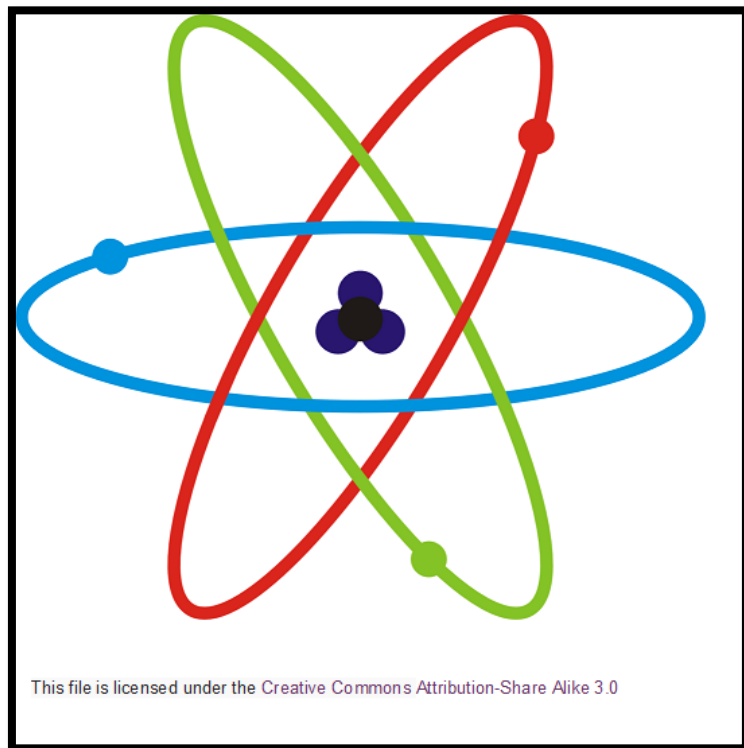
In order to be successful on your DAT, OAT, etc. exam we need to go through the various chapters and present the basic concepts as well as an understanding of the material.

Chapter 1 - Biological Concept Introduction

Basic Chemistry Review

Let us review a few terms from chemistry:

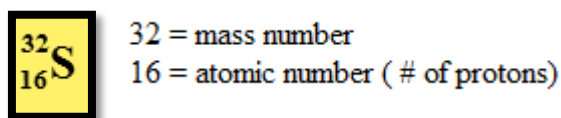
Atoms are made up of three main particles: **protons, neutrons, and electrons**.



As far as mass goes: neutron > proton > electron

The nucleus contains the **nucleons** (protons and neutrons), while the electrons reside outside the nucleus.

Consider:



A charged particle is an **ion**. We can see a positive ion (**cation**) or negative ion (**anion**).

If neutral, # protons = # electrons

Thus, $^{12}_6\text{C}$ has 6 protons and 6 electrons.

$^{16}_8\text{O}^{--}$ has 8 protons, but 10 electrons since -- means we added an additional two electrons.

$^{27}_{13}\text{Al}^{+3}$ has 13 protons, 10 electrons, and $27 - 13 = 14$ neutrons.

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Note: Mass # - Atomic # = Neutron #

Atoms of the same element represent **isotopes**.

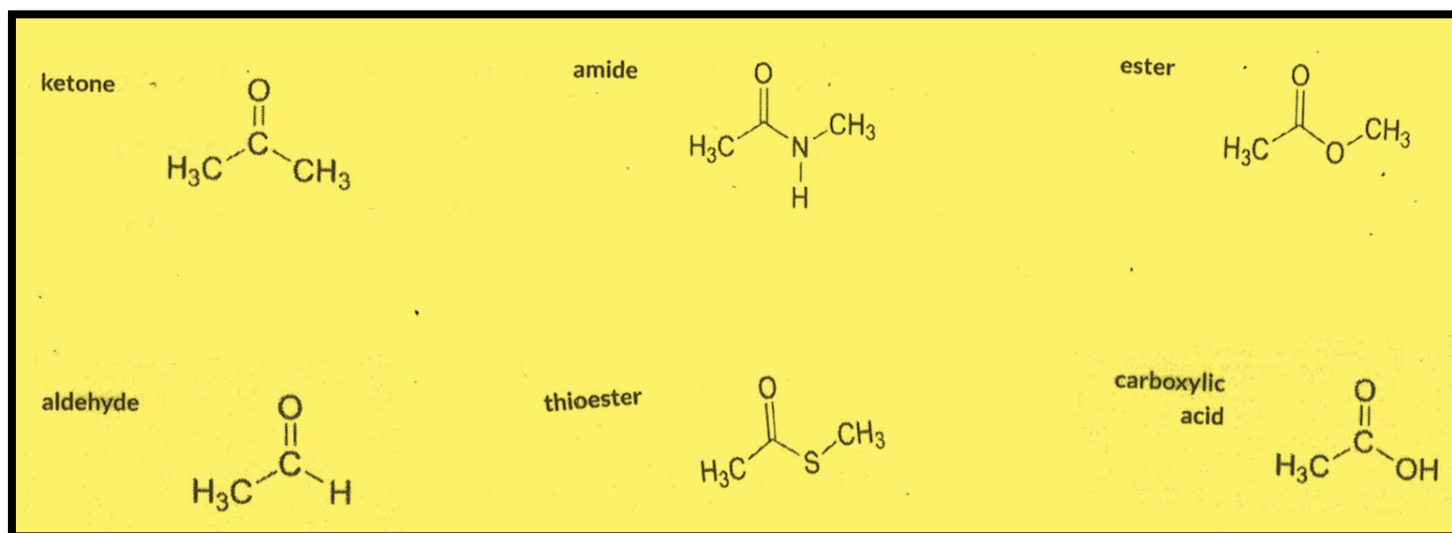
$^{12}_6\text{C}$, $^{13}_6\text{C}$, $^{14}_6\text{C}$ are isotopes.

Notice an isotope has the same atomic #, but different masses and different number of neutrons.

C, H, N, and O surely are the “big boys” when it comes to biology. Why?

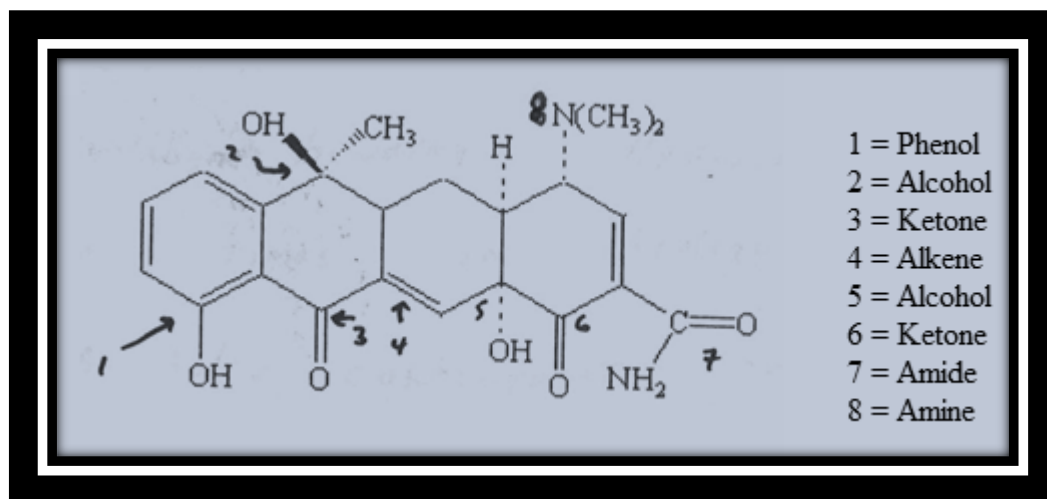
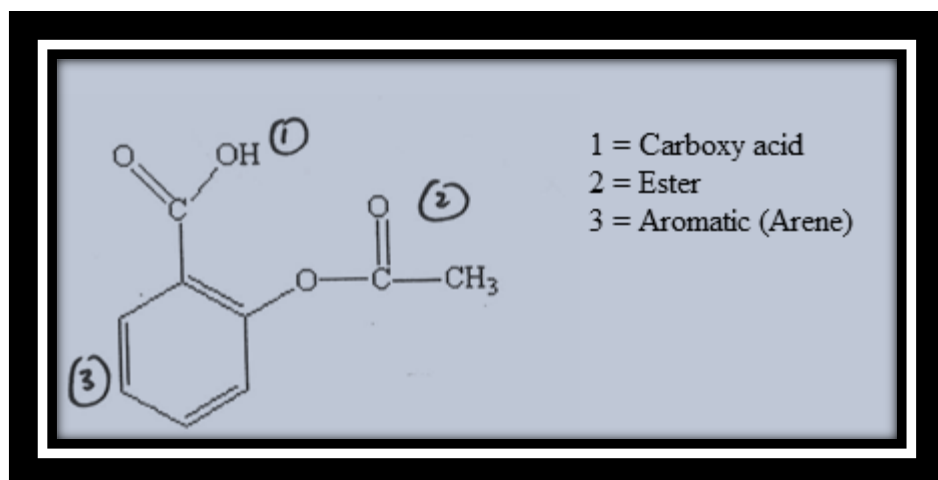
First of all, they are small elements which are able to form strong, stable, bonds. C, also has the ability to form single or multiple bonds as well as rings with itself and other atoms. This all leads to great variety of 3-D structures that are necessary for biological recognition.

In biology, we will come across many different atoms arranged and connected differently. We call this a **functional group**. This atom arrangement will dictate the chemical and physical properties of the molecule. **Some functional groups are shown below:**

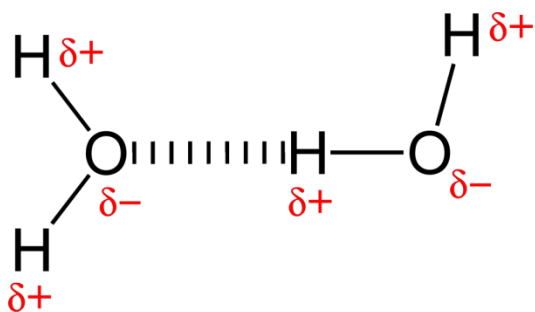


I will label a few functional groups, **see what you know**:

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H₂O is the **universal** solvent, and is capable of H-bonding with itself. This is what accounts for its high boiling point, melting point, ΔH vaporization, and most of its properties.



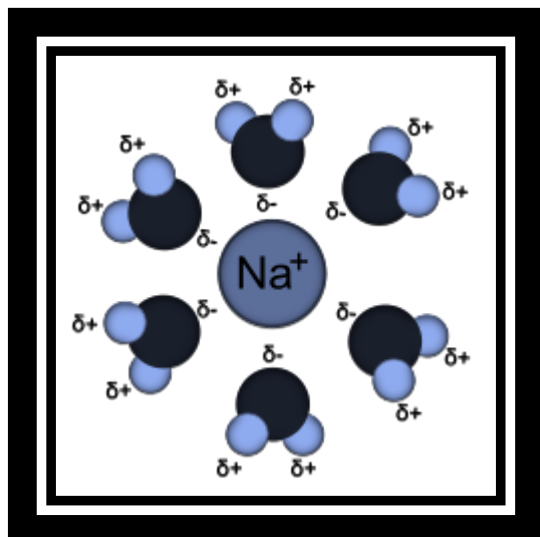
H₂O is a **bent** molecule at about 105°, it is a polar molecule capable of forming 4 H-bonds.

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Whenever hydrogen is bonded to an O, N, F, we see hydrogen bonding. Hydrogen bonding will be presented many times in biology. You will see it in the DNA helix, carbohydrates, proteins, and H₂O.

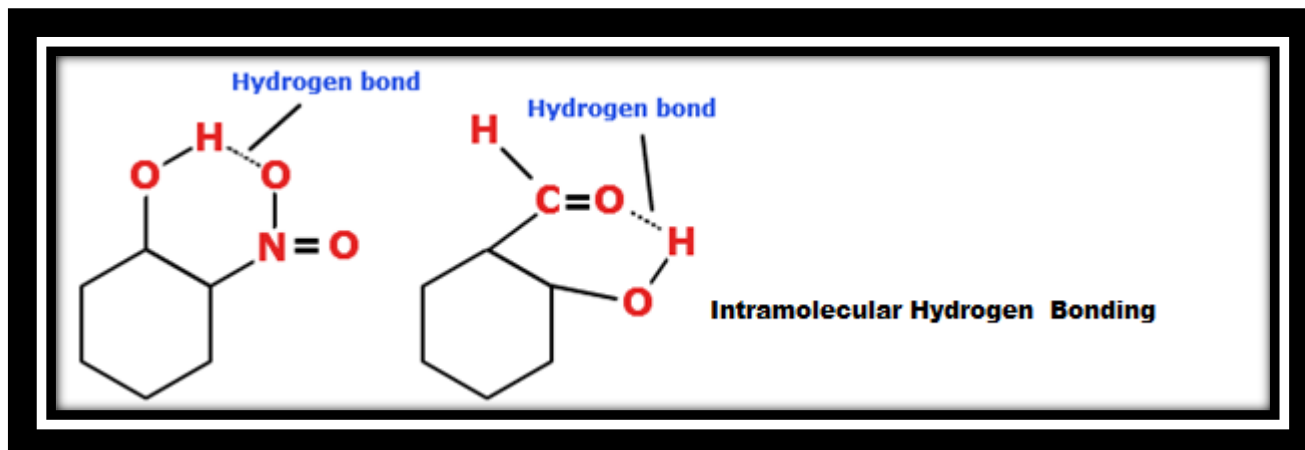
H₂O is a polar molecule; thus, it has a dipole.

Let us see how an ion is solvated:

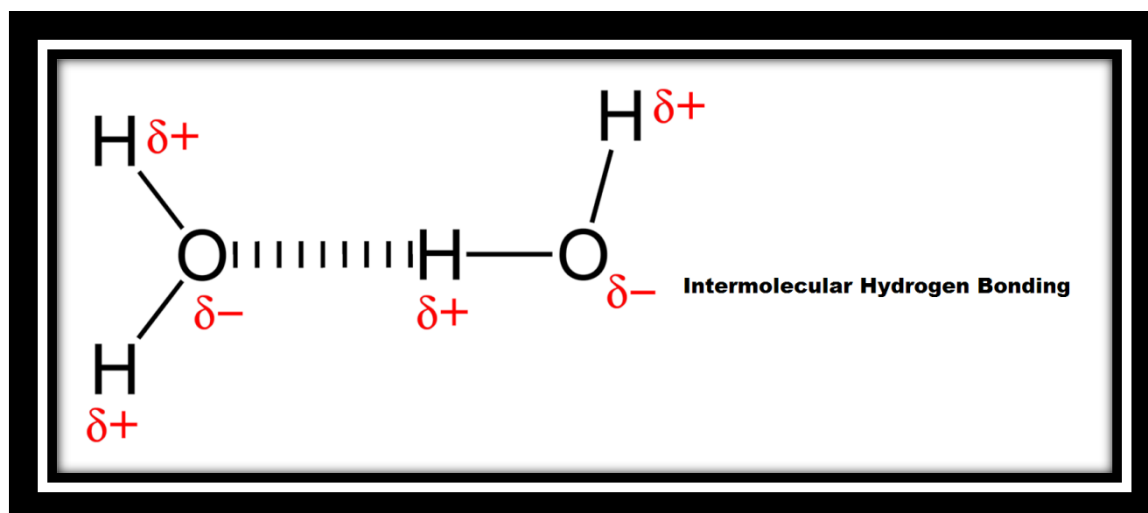


A H-bond can be: intermolecular or intramolecular

Let us consider the following:



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If a molecule shares electrons equally we call it a **nonpolar covalent bond**. If the electrons are shared unequally, we call it a **polar bond**.

As a nice rule of thumb... polar molecules attract to polar molecules, nonpolar molecules attract to nonpolar molecules.

Between both polar and nonpolar molecules is another very weak attractive force called a **Van der Waals interaction**. A gecko lizard can walk up a wall due to this weak attraction between a surface and its toe!! We will see Van der Waals in molecules such as proteins, for they help to reinforce the three-dimensional shape.

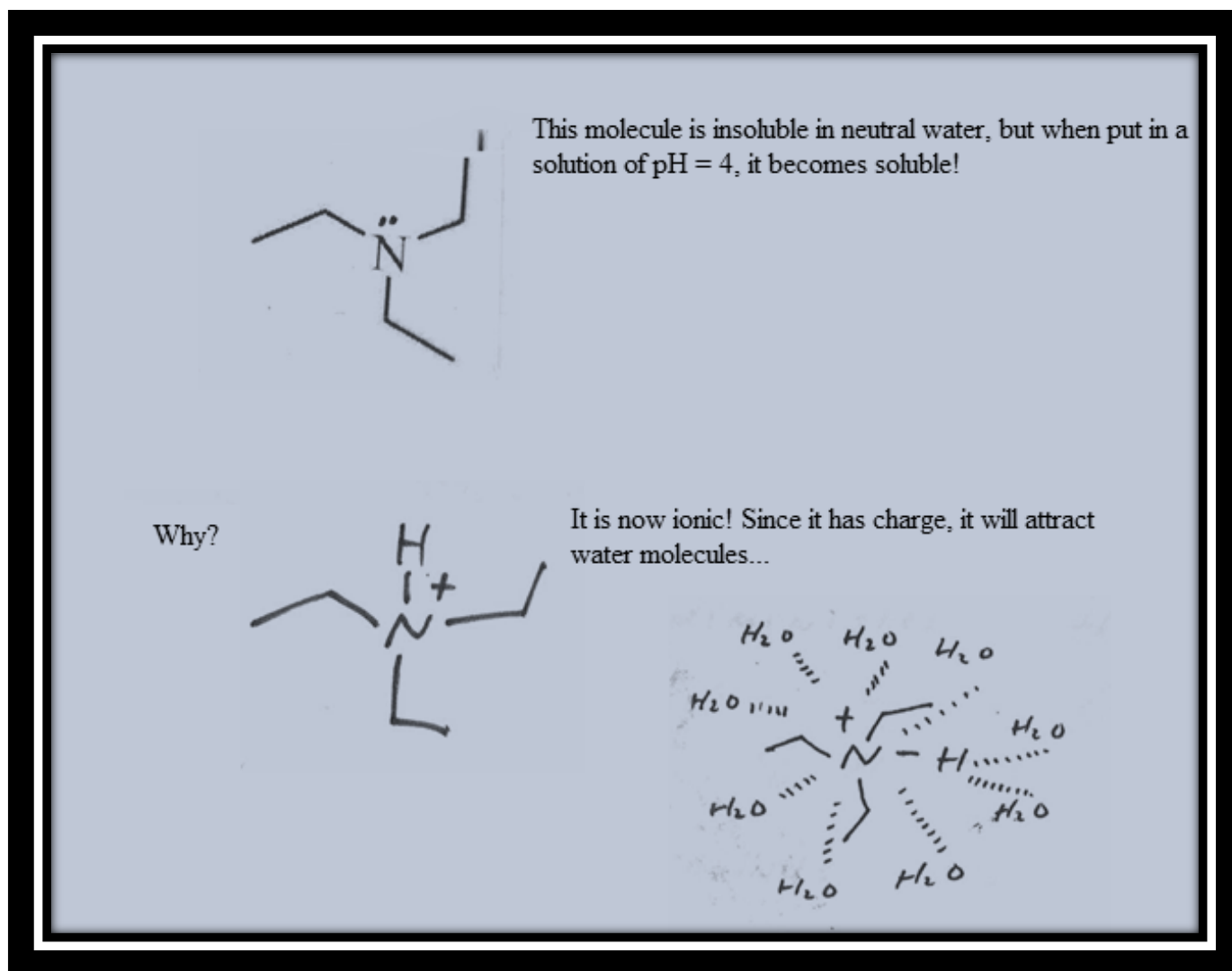
Ionic bonds are seen when electrons are transferred usually between a metal and nonmetal. Also, if you see a +N, you have an ionic bond!

NaCl, MgBr₂, NH₄Cl are all examples of ionic compounds. A nice rule of thumb is that most polar molecules and ionic compounds are water soluble!

Why can't a hydrocarbon such as hexane dissolve in water?

Water molecules are very tightly attracted to each other by extensive hydrogen bonding. Even though water may be weakly attracted to hydrophobic molecules by the Van der Waals forces, water would have to break many favorable H-bonds in order to make room for a hydrophobic solute. Since the water gets no favorable interactions back, this is not a spontaneous process and the two molecules do not mix.

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Here is a challenge problem I do with my students. I hope you enjoy it!

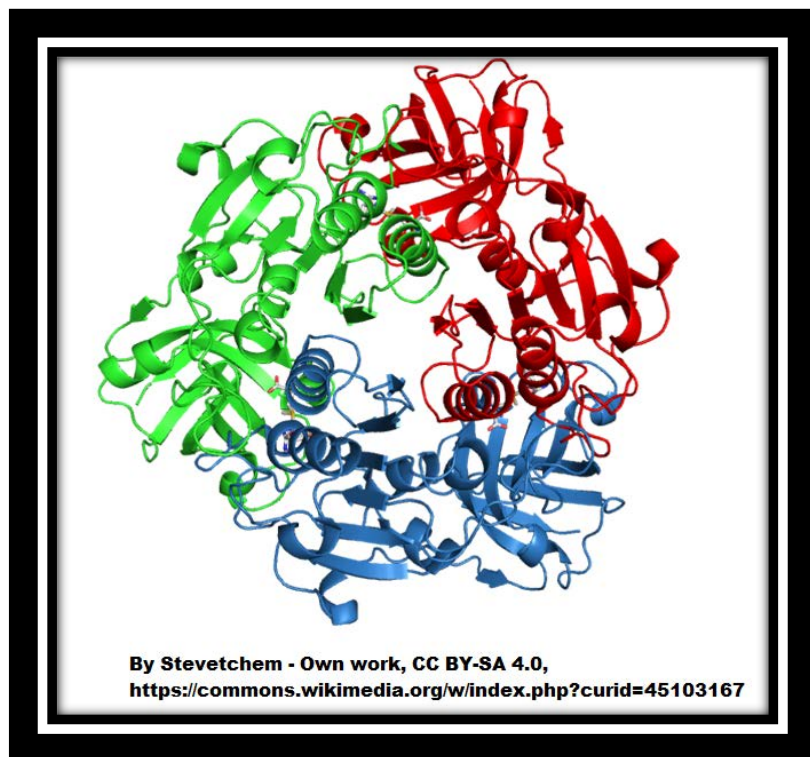
Electrostatic interactions are relatively weak (similar in strength to dipolar and H-bond interactions) when they exist on the surface of a soluble protein. However, they can be very strong when they are buried in the interior of the protein. Explain.

On the surface of the protein the charges are in a hydrophilic, aqueous environment. H₂O is very polar (as noted by its high dielectric constant) and the H₂O “shields” the charges from each other, so they interact weakly. There is no H₂O in the hydrophobic interior of the protein, so the charges interact strongly!!

Note: H₂O diminishes the strength of electrostatic interactions by a factor of 80, the dielectric constant of H₂O!!! As you have just seen, H₂O surrounds the + or – charges to form a “solvent shell” ... these solvent shells produce an electric field, which opposes the fields produced by the ions!!

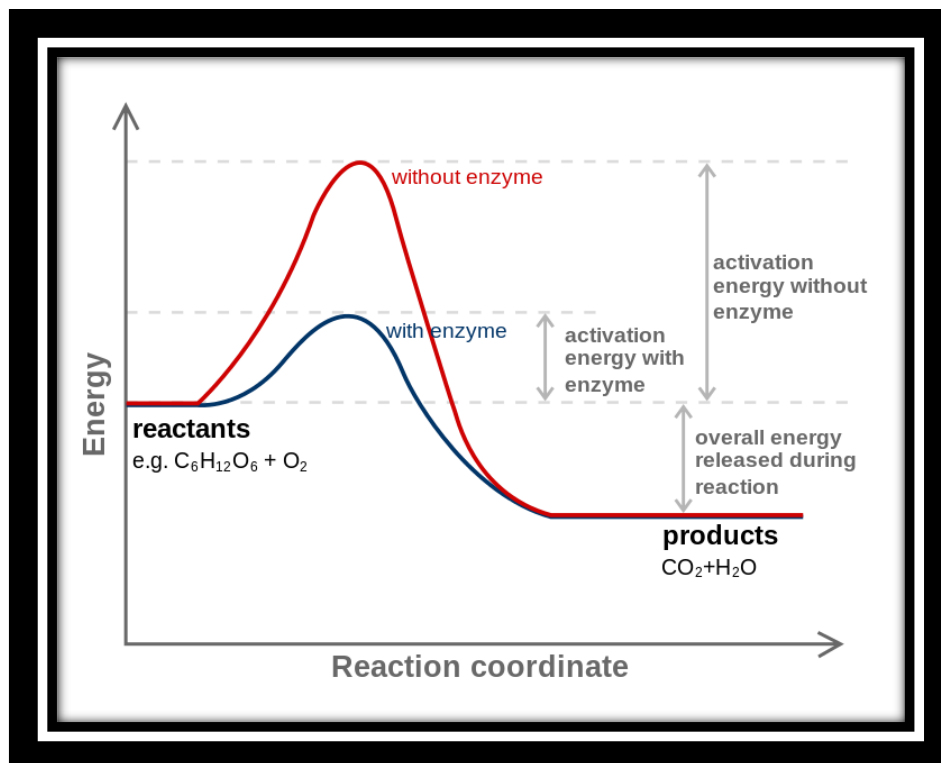
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Many reactions in biology and biochemistry require catalysts which we call **enzymes**! Enzymes are proteins and unlike the catalysts in organic chemistry are **highly specific** with 3-D shapes...



Enzymes can increase the rate of a biological reaction millions of times by lowering the E_a for forward and reverse reactions. (E_a = energy of activation).

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Thermodynamic Parameters

Let me review with you some **thermodynamic parameters**:

ΔG : Free Energy... the energy available to do work

- a) $+\Delta G$ reaction is **non-spontaneous**
- b) $-\Delta G$ reaction is **spontaneous**

★ A spontaneous reaction is one that goes to completion (i.e. to the right) by over 50%.

$\Delta G = 0$ at equilibrium.

Remember, a spontaneous reaction does not imply speed, it can take years, and still be spontaneous!

★ Endergonic: $+\Delta H$, $+\Delta G$

★ Exergonic: $-\Delta H$, $-\Delta G$

ΔH : Enthalpy

Almost all exothermic (heat-releasing) processes are spontaneous!

e.g. Combustion of a fuel oxidation of glucose

Entropy: ΔS

This is the amount of randomness or disorder in a system.

Solid $\longrightarrow -\Delta S$

Gas $\longrightarrow +\Delta S$

$$\Delta G = \Delta H - T\Delta S$$

Under what conditions of ΔH and ΔS would a reaction always be spontaneous?

★ A $-\Delta H$ and $+\Delta S$ will guarantee that a reaction will be spontaneous at all temperatures.

Let K = Equilibrium constant; $K = \frac{[\text{Products}]}{[\text{Reactants}]}$

★ Do not use solids or pure liquids.

If K is large, i.e. >1 , reaction is favored in the forward direction. If not, if $K < 1$, reaction is favored in the reverse direction.

Is ΔG related to K ? Yes...

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$$\Delta G = -2.303RT\log K \text{ or } \Delta G = -RT\ln K$$

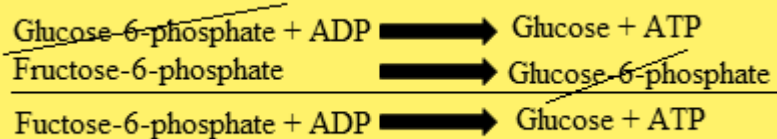
Let's do a simple problem:

- a) Glucose + ATP $\longrightarrow$ Glucose-6-phosphate + ADP $\frac{\Delta G^\circ}{-4000 \text{ cal}}$
b) Glucose-6-phosphate $\longrightarrow$ Fructose-6-phosphate +400 cal

Find ΔG° for: Fructose-6-phosphate + ADP $\longrightarrow$ Glucose + ATP

Solution

Reverse b, Reverse a



$\Delta G^\circ = +4000 - 400 = 3600 \text{ cal}$, reaction is endergonic.

PH Scale



Acids will donate H^+ ions



Bases will accept H^+ ions

Under 7 $\longrightarrow$ Acidic $\longrightarrow [H_3O^+] > [OH^-]$

Over 7 $\longrightarrow$ Basic $\longrightarrow [H_3O^+] < [OH^-]$

At 7 we see neutrality $[H_3O^+] = [OH^-]$

Recall:

$$pH = -\log[H_3O^+]$$

$$pOH = -\log[OH^-]$$

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$$\text{pH} + \text{pOH} = 14$$

$$\text{pK}_a = -\log K_a$$

★ A large K_a = small pK_a means a strong acid!!

e.g. The K_a of acetic acid is 1.8×10^{-5} . CH_3COOH is Acetic Acid.

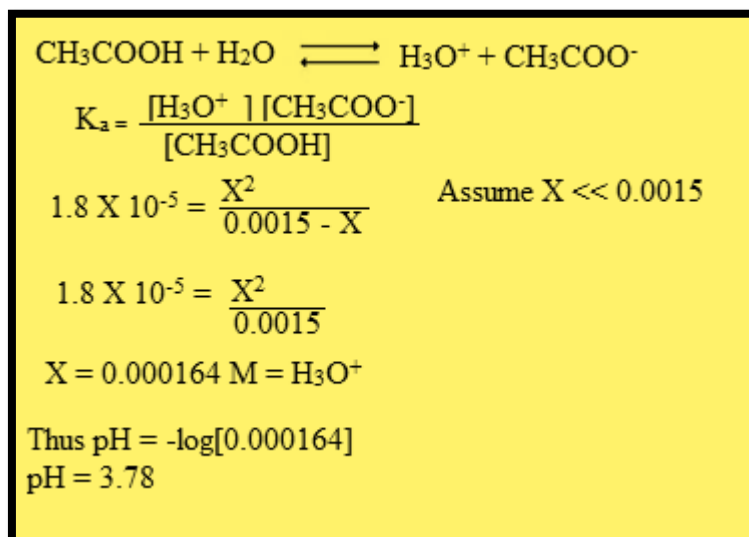
a) Find pK_a

b) Find pH of a 0.0015 M solution

Solution:

a) $\text{pK}_a = -\log 1.8 \times 10^{-5} = 4.74$

b)



★ You can do these with a calculator! The DAT will give you much easier numbers to work with.

Buffers

A buffer is a compound that resists pH change. We see a weak acid or base and its salt.

e.g.

Acetic Acid and Sodium Acetate

Glycine and Glycine Hydrochloride

To do buffers, use the **Henderson-Hasselbach Equation**:

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$$\text{pH} = \text{pK}_a + \text{Log} \frac{[\text{base}]}{[\text{acid}]}$$

Problem 1:

A buffer is composed of 0.001M Acetic Acid and 0.01M Sodium Acetate. [$K_a = 1.8 \times 10^{-5}$]. Find the pH of this buffer.

$$\text{pK}_a = -\text{Log}K_a = -\text{Log} 1.8 \times 10^{-5} = 4.74$$

$$\text{pH} = \text{pK}_a + \text{Log} \frac{[\text{base}]}{[\text{acid}]}$$

$$\text{pH} = 4.74 + \text{Log} \frac{0.01}{0.001}$$

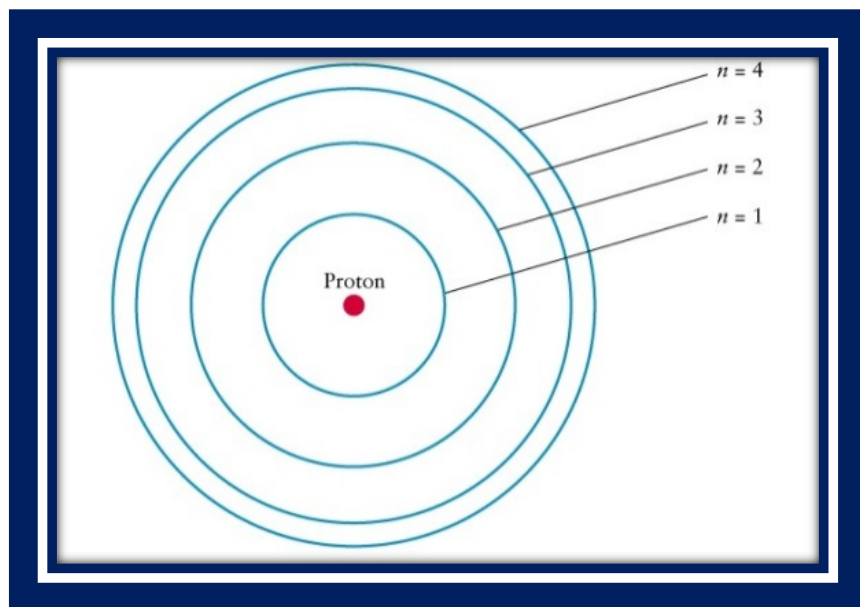
$$\text{pH} = 4.74 + \text{Log}10$$

$$\text{pH} = 5.74$$



No need to do more here, the DAT Destroyer will pick this up in General Chemistry

The Atom



Let us return to the atom briefly. I am sure I terrorized some of you already, but relax... not much math will be here until we visit the dreaded Hardy-Weinberg equation.

An orbital represents an area of space where there is a high probability to finding an electron.

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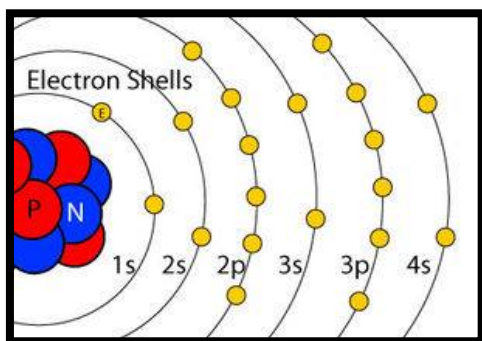
Consider the atom:

Let N = Principle energy level

Each N can be divided into a smaller area of space called a sublevel. Sublevels include: s, p, d, and f.

Now... each sublevel is made of “parts” or regions called orbitals.

I will make a nice summary table for you!



Sublevel	# of Orbitals	Max # of electrons
s	1	2
p	3	6
d	5	10
f	7	14

★ Each orbital can hold a maximum of two electrons

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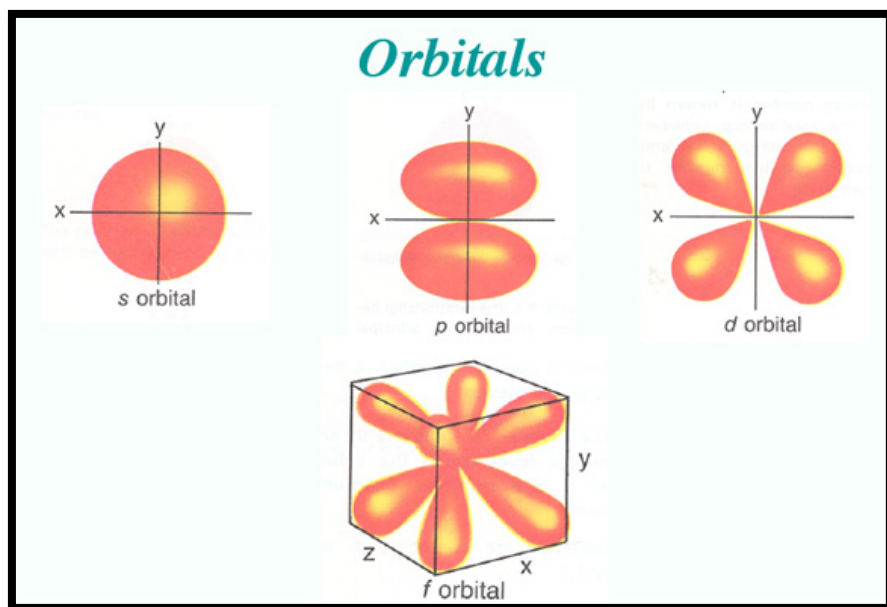
Write the configuration for:

- 1) $^{27}_{13}\text{Al}$
- 2) $^{12}_6\text{C}$
- 3) $^{24}_{12}\text{Mg}^{++}$

Solutions

- 1) $1s^2 2s^2 2p^6 3s^2 3p^1$
- 2) $1s^2 2s^2 2p^2$
- 3) $1s^2 2s^2 2p^6$ (careful! It has $10e^-$)

Orbitals can have different shapes. I hope you can recall these:



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Energy



Energy can be put into two categories (**DAT favorite!**):

- a) **Kinetic:** energy of motion (e.g. blood flows)
- b) **Potential:** energy that is stored (e.g. glycogen)

Classical mechanics classify all energy as either kinetic or potential, there are other energy forms.

- a) Gravitational
- b) Electrical
- c) Magnetic
- d) Nuclear
- e) Thermal
- f) Mechanical

Can you have both kinetic and potential? Indeed so!!

You ski down a mountain... as you go down the slope, you lose height (potential energy), but you pick up speed (kinetic energy).

In bio we often see one form of energy being transferred and converted to another.

★ Temperature is a measure of the average kinetic energy

Two must- know formulas:

$$F = 1.8C + 32$$

$$K = C + 273$$

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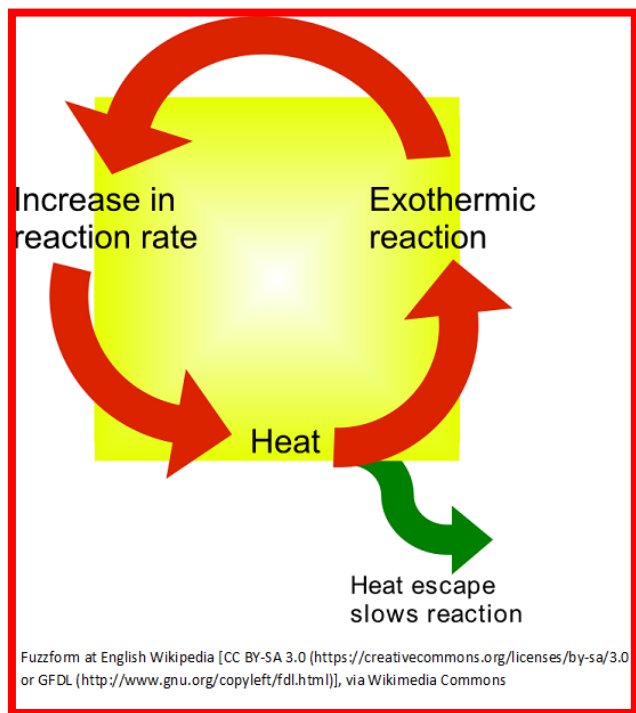
Laws of Thermodynamics

1st Law of Thermodynamics: Under ordinary conditions, energy can neither be created nor destroyed. Energy can only be transferred or changed from one form to another.

2nd Law of Thermodynamics: The entropy (disorder) of the universe is increasing over time. This law also states that all processes involve heat loss, with no process 100% efficient.

3rd Law of Thermodynamics: As the temperature approaches absolute zero (-273°C or 0 Kelvin), the entropy of a system is minimum!

Heat



A quick review of heat:

Heat is the transfer of thermal energy between two bodies. Heat moves from the hot object to the cold object.

Three system types:

1) Open System: mass and energy can exchange

e.g. H₂O in an open container

2) Closed System: allows energy to transfer, but not mass

e.g. H₂O in a closed flask

3) Isolated System: Neither energy nor mass can transfer

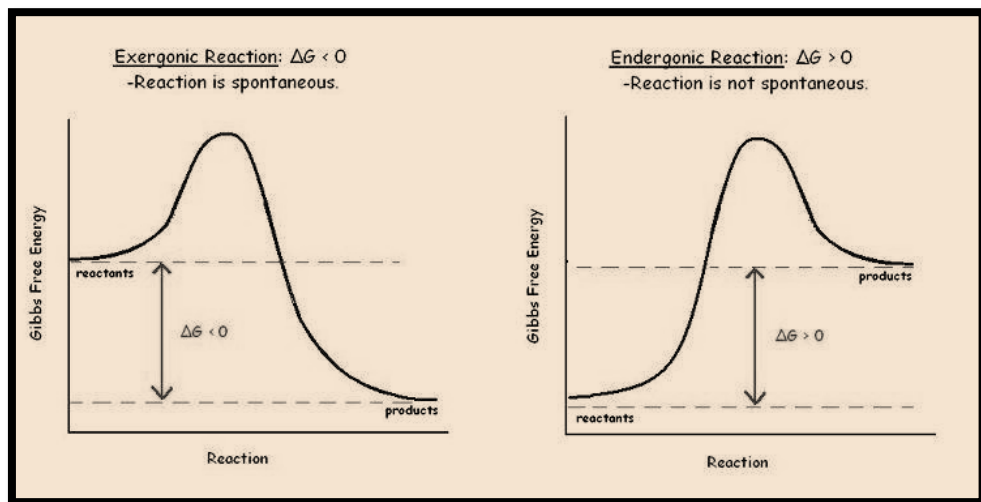
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e.g. H_2O in a flask that is closed and placed in a vacuum jacket.

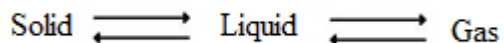
Exothermic Reactions: give off heat... surroundings get hot

Endothermic Reactions: absorb heat... surroundings get cold

Recall the energy-profile diagrams:



Recall:



S $\longrightarrow$ L is melting ($+\Delta H$)

L $\longrightarrow$ S is freezing ($-\Delta H$)

L $\longrightarrow$ G is vaporizing (boiling) ($+\Delta H$)

G $\longrightarrow$ L is condensing ($-\Delta H$)

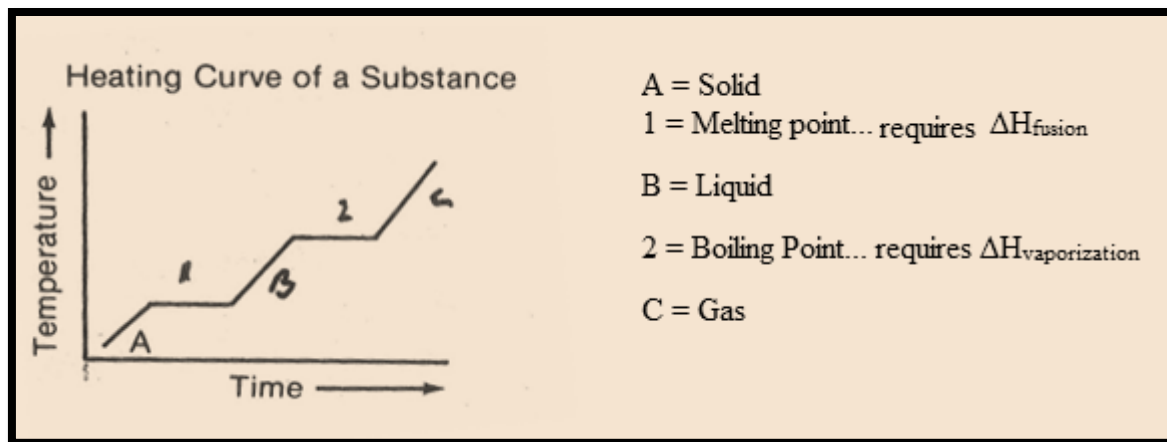
S $\longrightarrow$ G is sublimation ($+\Delta H$)

G $\longrightarrow$ S is deposition ($-\Delta H$)

To convert a unit of solid $\longrightarrow$ liquid = **Heat of Fusion**

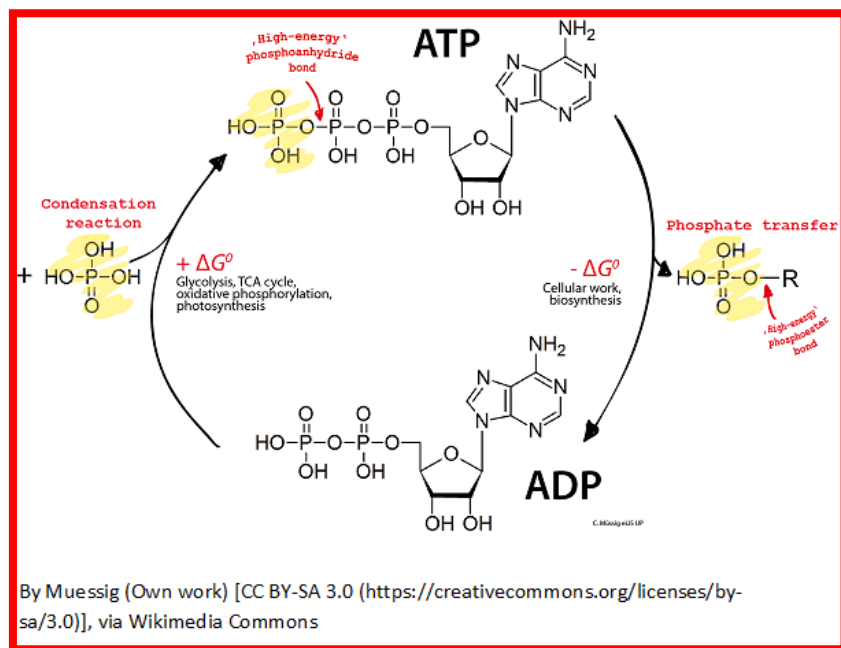
To convert a unit of liquid $\longrightarrow$ gas = **Heat of Vaporization**

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ATP and Cell Metabolism



What is ATP?

This is Adenosine Triphosphate:

This molecule is a carrier of free energy. When hydrolyzed, a large amount of free energy is given off.

Now, the energy liberated is harnessed to drive reactions that require energy input such as skeletal muscle contraction.

Bottom Line for the DAT: ATP allows endergonic reactions to become exergonic.

ATP represents the universal currency of free energy in all biological processes.

We will now turn to a new area of biochemistry called metabolism.

The thousands of enzyme-catalyzed chemical reactions in cells are functionally organized into many different sequences of consecutive reactions called pathways, in which the product of one reaction becomes the reactant in the next.

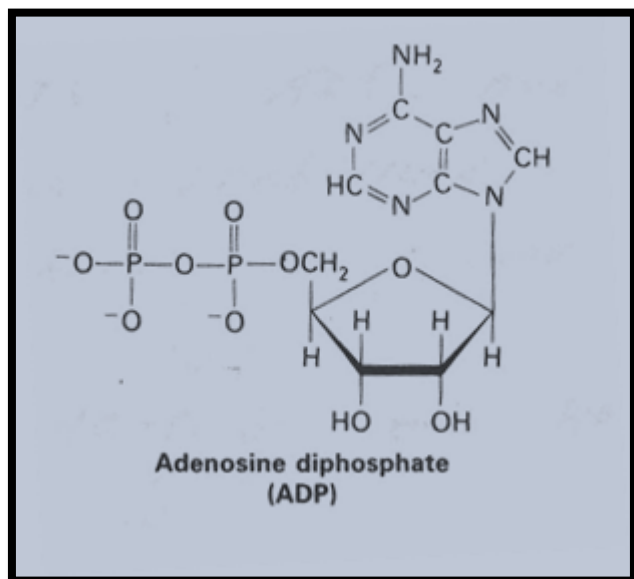
Some of these sequences of enzyme-catalyzed reactions degrade organic nutrients into simple end products, in order to extract chemical energy and convert it into a form useful to the cell. Together these degradative, free-energy yielding reactions are designated as **catabolism**.

Other enzyme-catalyzed pathways start from small precursor molecules and convert them to progressively larger and more complex acids, these pathways need energy input and are called **anabolism**.

The network of enzyme-catalyzed pathways make-up the **cell metabolism**.

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Cells capture, store, and transport free energy in a chemical form. ATP functions as the major carrier of chemical energy in all cells. ATP carries energy between metabolic pathways by serving as the shared intermediate that **“couples”** endergonic (non-spontaneous) to exergonic (spontaneous) ones. The terminal phosphate group of ATP is transferred to a variety of acceptor molecules, which are thereby activated for further chemical transformation. The ADP that remains is recycled to become ATP. As you can see, ATP is the major “crosslink” between catabolic and anabolic pathways.



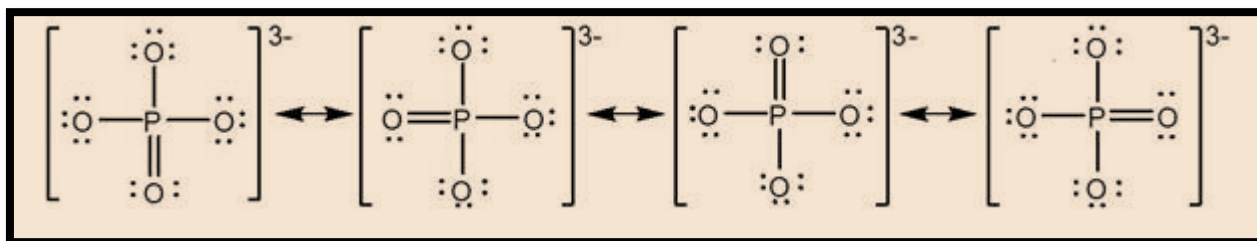
$$\Delta G^\circ = -7.3 \text{ Kcal/mol}$$

ATP hydrolysis as seen was -7.3 Kcal/mol. This is a “high” value, meaning that ATP has a high phosphoryl group transfer potential.

Why does ATP possess such a great phosphoryl potential?

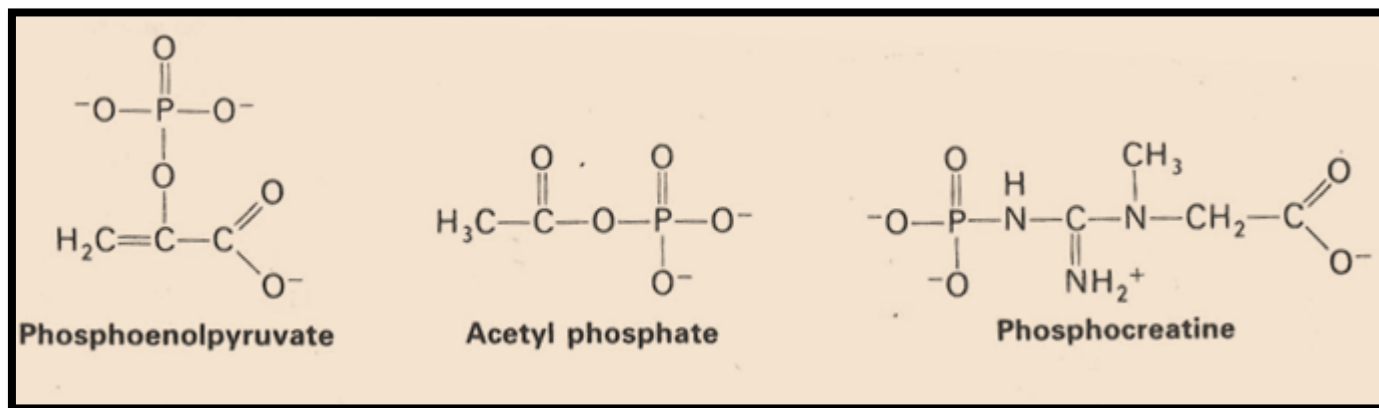
Two main reasons:

- 1) At pH of 7, ATP is very negatively charged... Actually, it carries four negative charges which are close together. Therefore, as you can imagine, these charges strongly repel on another. When ATP is hydrolyzed, we decrease this repulsion.
- 2) The products, ADP and P_i are more resonance-stabilized than ATP alone. Let's have a look at P_i :



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This doesn't mean that ATP has the highest phosphoryl transfer potential (creatine phosphate, acetyl phosphate, phosphoenol pyruvate have higher), but it is very significant in terms of being able to transfer its phosphate group:



★ Vertebrate muscle contains creatine phosphate which readily transfers its phosphoryl group to form a high concentration of ATP during strenuous exercise.

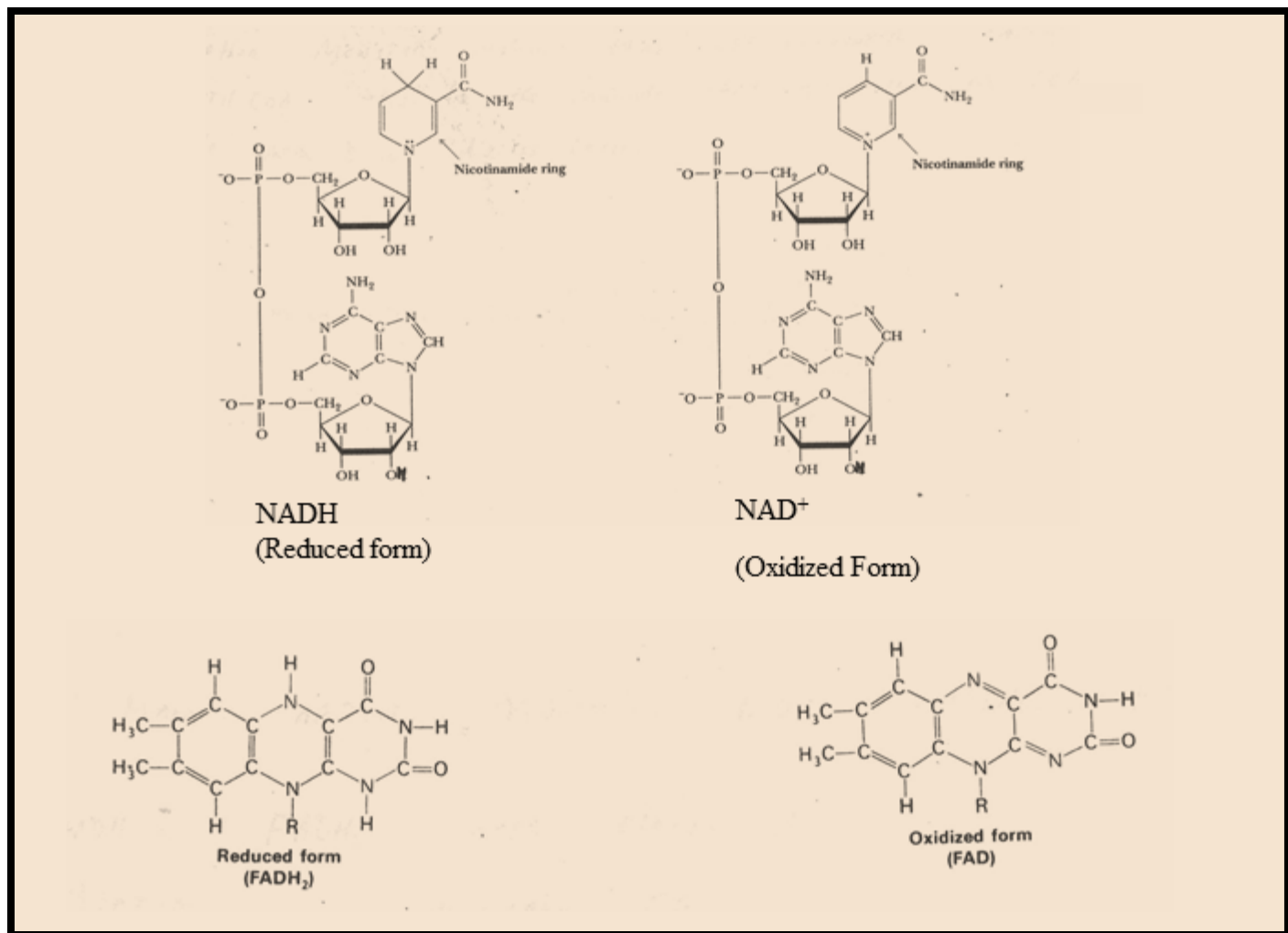
The body maintains the concentration of ATP in a steady state. The body makes ATP and breaks it down as needed to maintain homeostasis.

Chemotrophs derive free energy from the oxidation of fuel molecules.

NADH and FADH₂ represent the major electron carriers.

Did you ever wonder why we don't draw the structures out? Have a look...

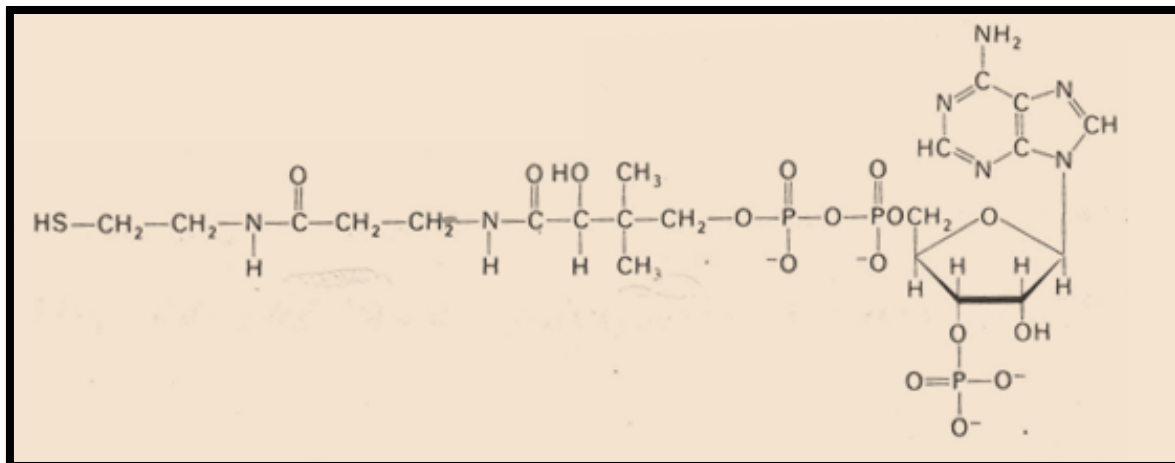
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No need to panic, but just wanted to show you.

Another monster molecule that you will encounter is called **Acetyl CoA**. This is the molecule that goes into the TCA cycle which I will discuss later.

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The hydrolysis of this molecule is huge!! The ΔG° is -7.5 Kcal/mol.



Many carrier molecules exist besides ATP...

NADH and FADH₂ carry electrons.

Biotin will carry CO₂

S-Adenosylmethionine (called SAM) carries CH₃ groups.

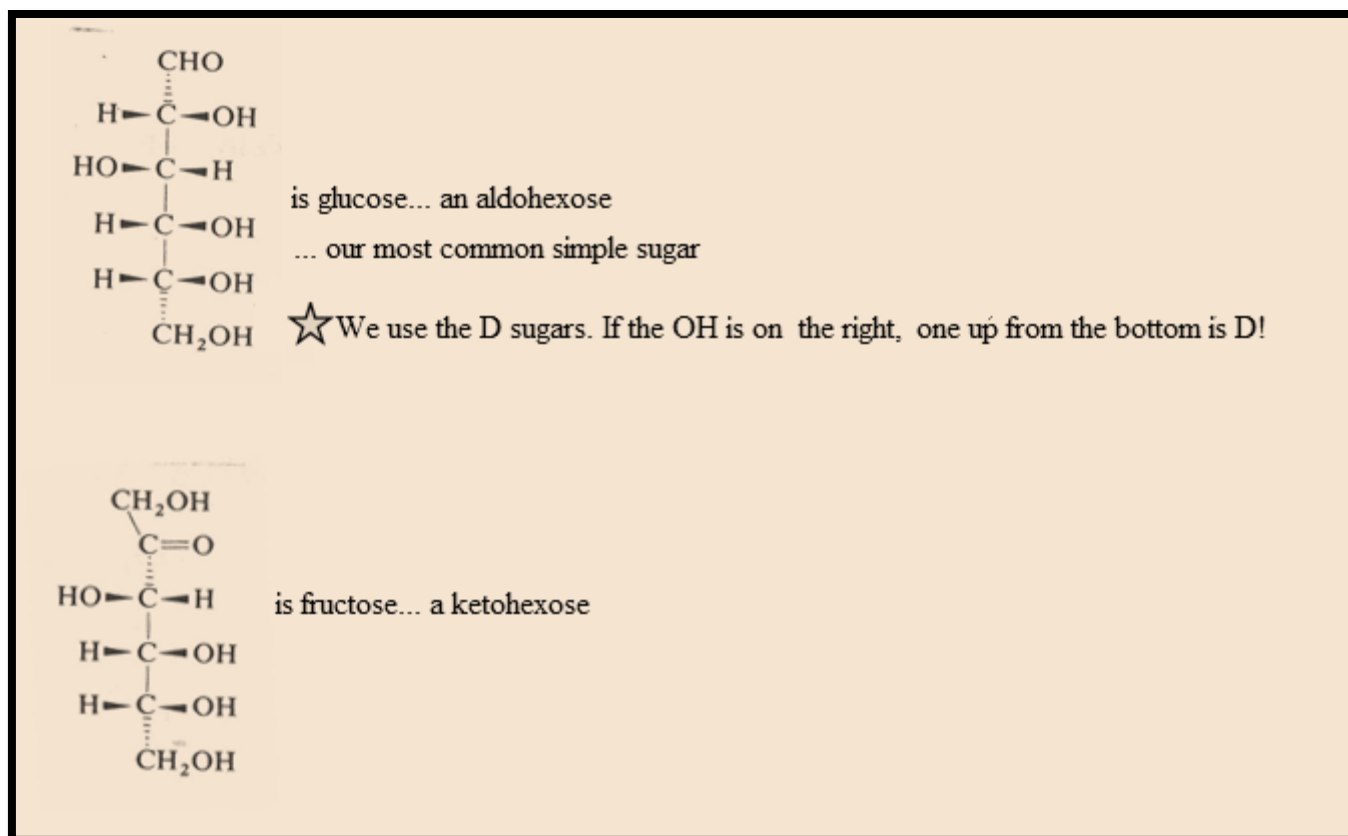
For the DAT... this will be fine. Details will be presented in graduate school.

We should be able to recognize some basic structures:

Carbohydrates

Commonly referred to as sugars and starches- polyhydroxy aldehydes and polyhydroxy ketones abound!!

Chapter 1 - Biological Concept Introduction



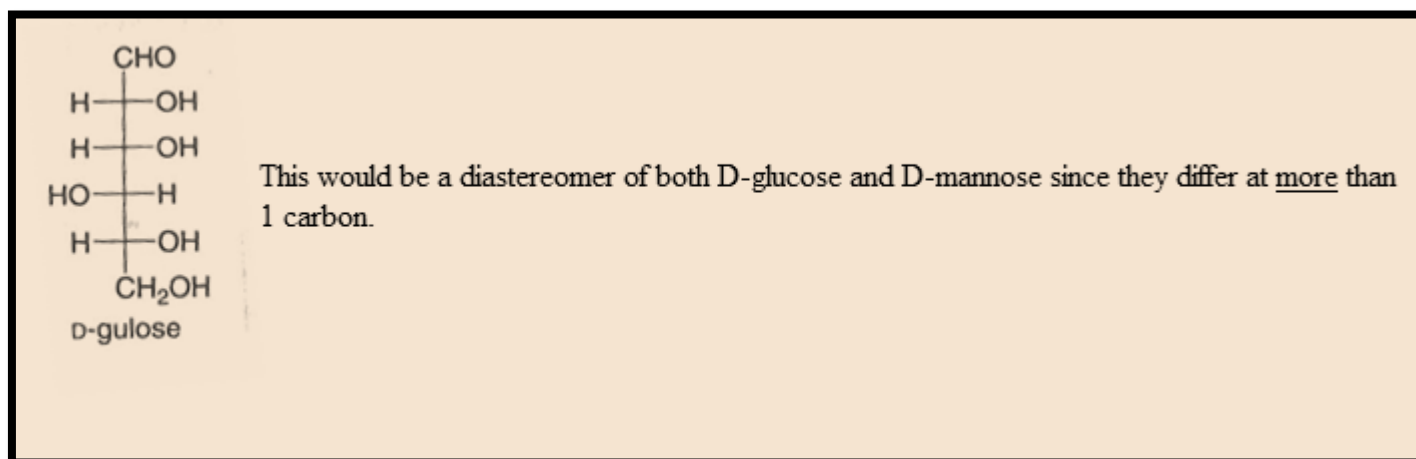
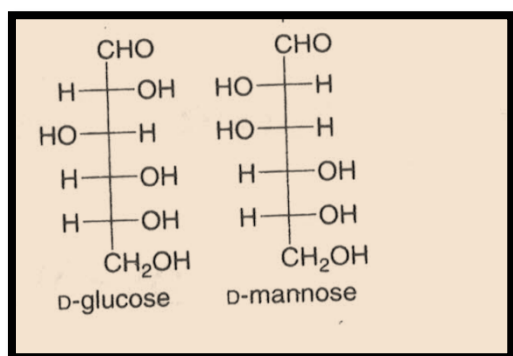
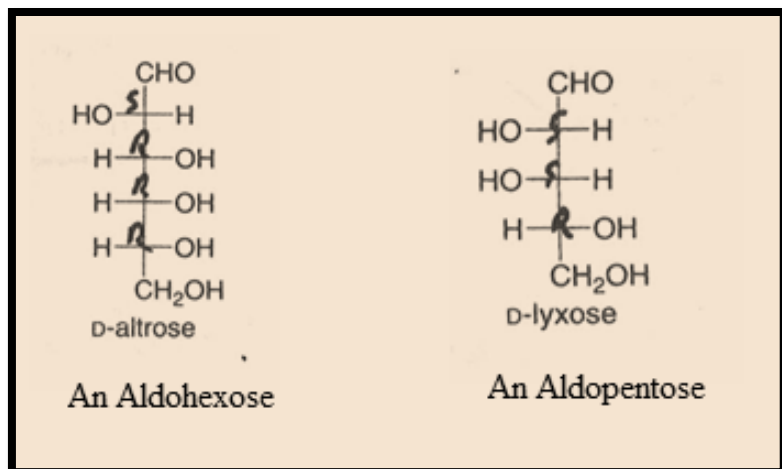
These are monosaccharides that cannot be hydrolyzed to simpler compounds. Carbohydrates represent a storehouse of chemical energy!

Here is an awesome trick you can use in sugar chemistry. If you are at a chiral carbon...

If the OH is on the **right**... R configuration

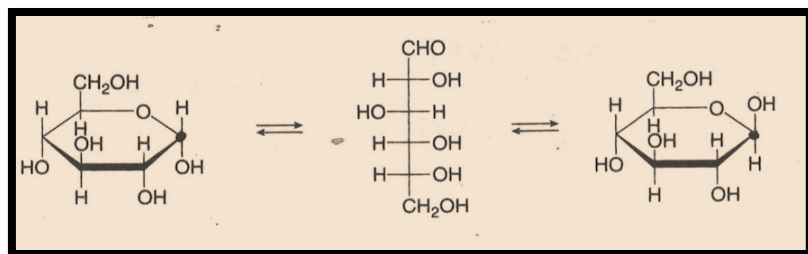
If OH is on the **left**... S configuration

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In bio, we usually draw our sugars in rings... which is the major structure that we normally prefer.

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I put a “dot” at C-1... this is the **anomeric carbon**.

If the OH is **down** at C-1... **alpha form**.

If the OH is **up** at C-1... **beta form**.

Alpha and beta sugars represent diastereomers called **anomers**.

Monosaccharides: single sugar

Disaccharides: two sugars

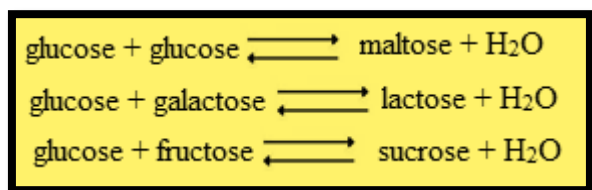
Trisaccharides: three sugars

Oligosaccharides: 4-10

Polysaccharides: usually over 10

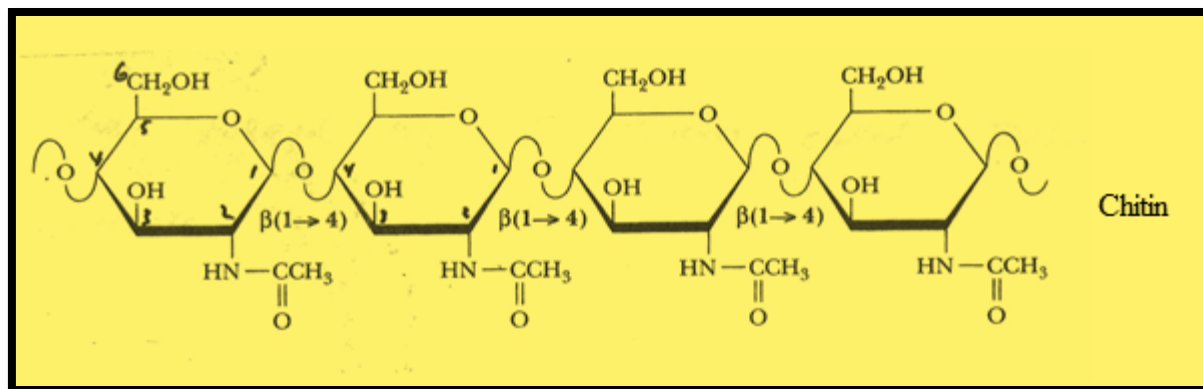
Monosaccharides	Disaccharides	Polysaccharides
Glucose	Maltose	Cellulose (β -glucose)
Galactose	Sucrose	Amylose (α -glucose)
Fructose	Lactose	Glycogen (branched)
Fucose (I'm serious!)	Gentobiose	Chitin
Mannose	Cellobiose	Amylopectin (branched)

Disaccharides are made by the linking of monosaccharides in a process called **dehydration synthesis**:



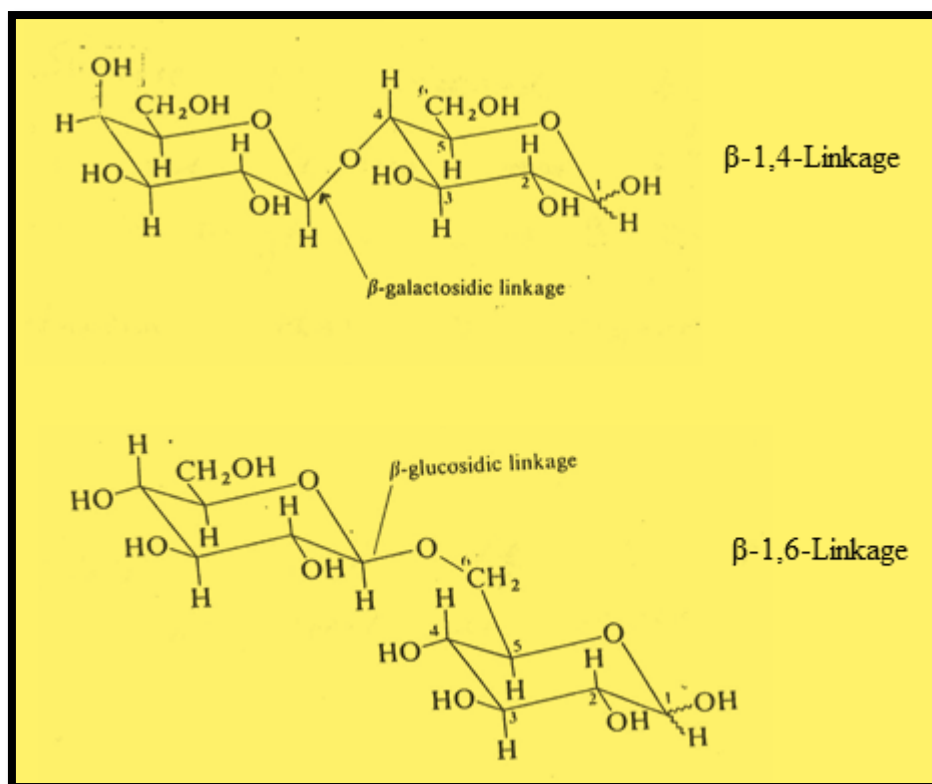
★ Chitin is a derivative of glucose. It is a component of cell walls of **fungi** and part of the **exoskeleton** of arthropods, such as crustaceans (lobsters, crabs, shrimp) as well as insects.

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I numbered it for you. I hope you can see it is a 1, 4-linkage. If it goes up at C-1... it is the beta linkage.

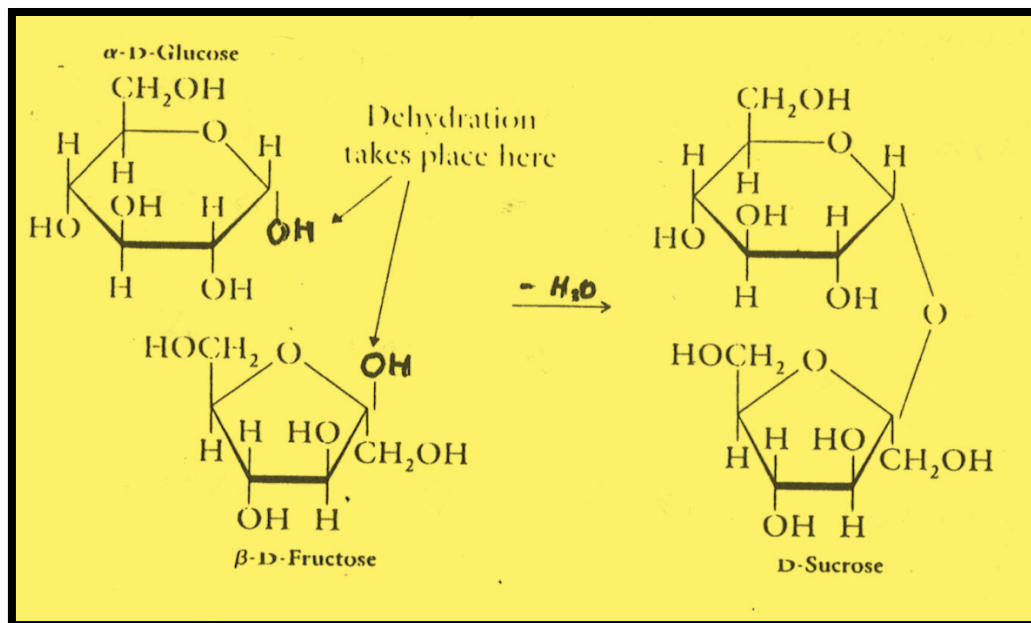
Here are a few other linkages for you to **simply recognize**. Do not get scared because I draw the six-membered ring in a chair. I will make a video in the near future to show you how. For bio, no need to worry.



Sugars are formed by the process called **dehydration synthesis**.

Let me illustrate:

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Sucrose is formed by a 1,2-linkage between glucose and fructose. It is exclusively made by linking α -D-glucose with β -D-fructose.

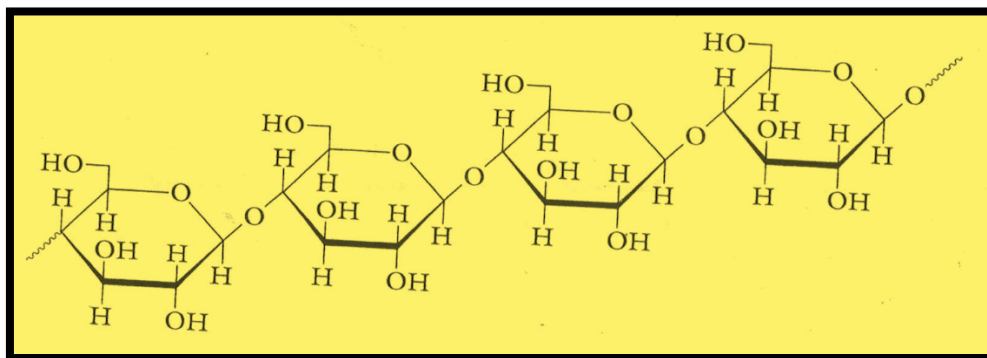
Describe the mechanism that is responsible for this “exclusivity” of linkage.

There will be four possible ways to link the two... at least in theory:

- a) α, α
- b) α, β
- c) β, β
- d) β, α

It turns out that an enzyme helps to do the linking... as with all sugars being put together... these two sugars fit nicely into the enzymes binding pocket... evidently only when the α, β linking occurs do we see this correct fit into the binding pocket.

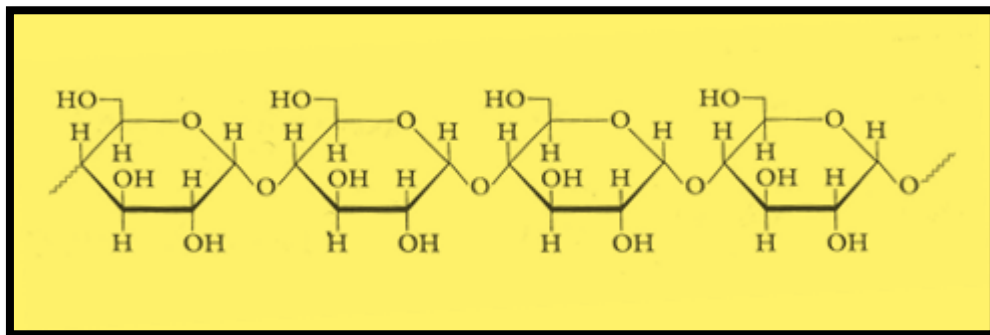
Below is **cellulose**: A linear polymer of glucose with β (1 $\rightarrow$ 4) glycosidic linkage. We as humans lack the enzyme to break this linkage! Cellulose is the most abundant compound in the biosphere!



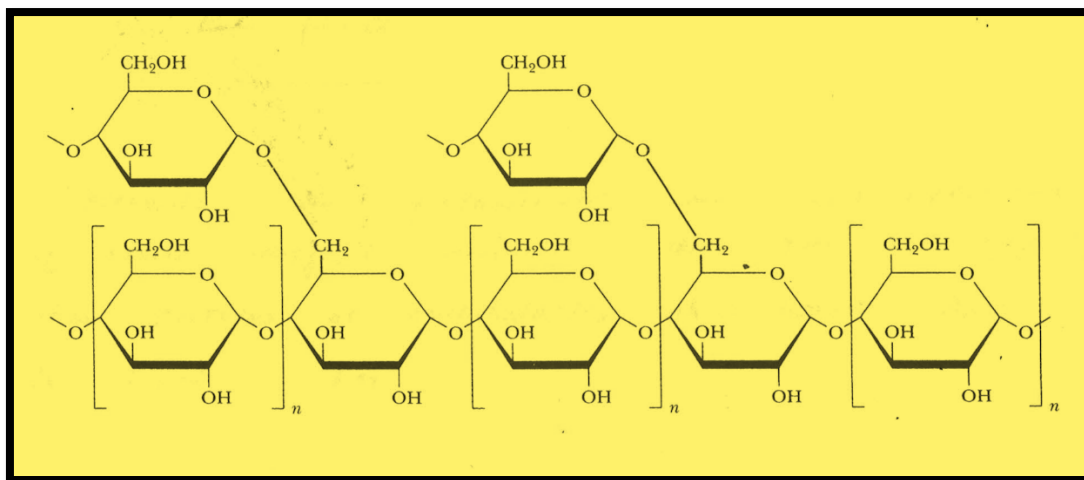
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Cotton is almost pure cellulose. Many different conformations are possible because of rotation about the many single bonds.

Below is **amylose**: a liner polymer of glucose with α (1 $\rightarrow$ 4)- glycosidic linkages. Most starch from plants is 20% amylose.



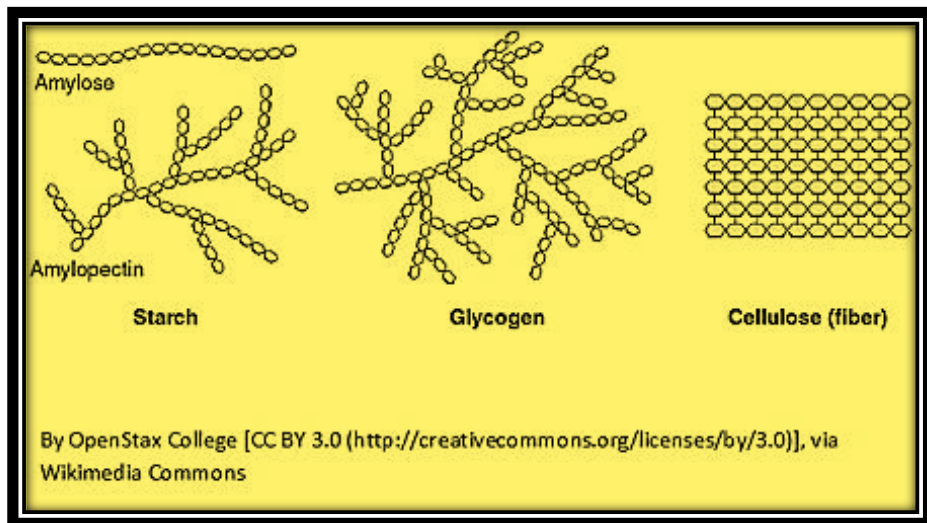
Below is **amylopectin**: a branched polymer of glycose, α (1 $\rightarrow$ 4) linkages mainly. Most starch from plants is 80% amylopectin... in addition it has α - 1, 6 linkages.



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Glycogen is animal starch. We store glucose as glycogen. Glycogen is found mainly in the liver and skeletal muscles. Again, it is a very large **branched** molecule similar to amylopectin. Glycogen, however is even more branched.

Glycogen is found in animal cells in granules, similar to the starch granules of plants.



Lipids

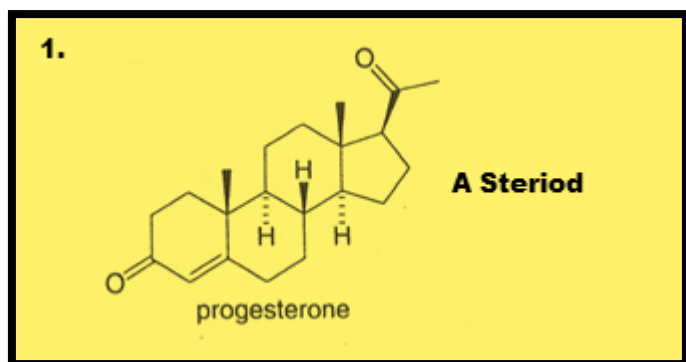
This represents the predominant and most efficient form of stored energy in animals. Lipids give off far more energy than proteins or carbohydrates when burned. Any excess lipids are stored as **fat**.

Lipids are:

- 1) Used for energy
- 2) Components of nerve cells
- 3) Used for protection
- 4) Membrane components

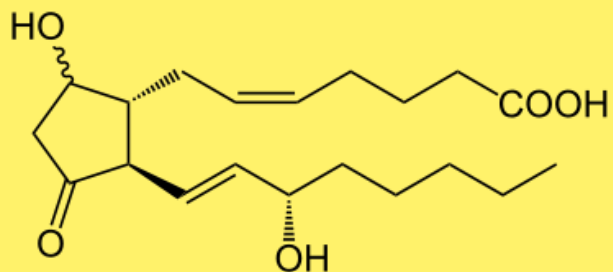
They have many diverse structures and are not identified by the presence of a particular functional group.

Let me show you what lipids can look like...



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2.



A Prostaglandin

Produced by most cells, they are involved with processes such as inflammation, blood clotting, and even the induction of labor.

3.



A triglyceride... made from glycerol and three fatty acids.

The fatty acids can be saturated... have only single bonds between carbons.



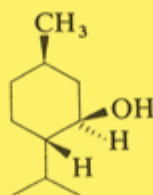
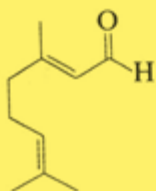
or they can be unsaturated... have one or more double bonds between carbons.



Double bond is almost always a "cis" double bond.

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4.



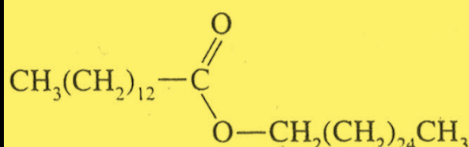
Terpenes

Produced mainly by plants.

Used in spices, perfumes, and medicines.

1. **Waxes**... these are esters of fatty acids and of long-chain alcohols.

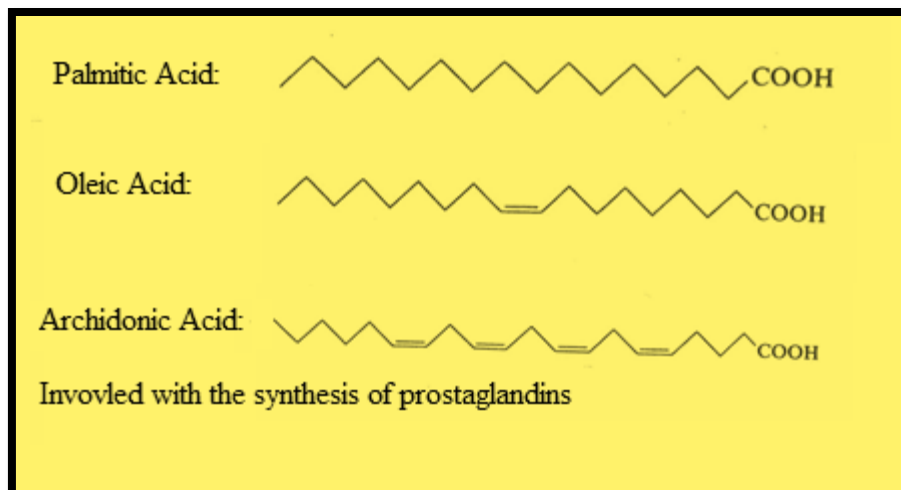
Beeswax is the structural material for the beehive. This is what it looks like:



Most **saturated fats** are **solids** at room temperature, while most **unsaturated fats** are **oils**. This does indeed have a health implication.

Which lipid do you think has the lowest melting point?

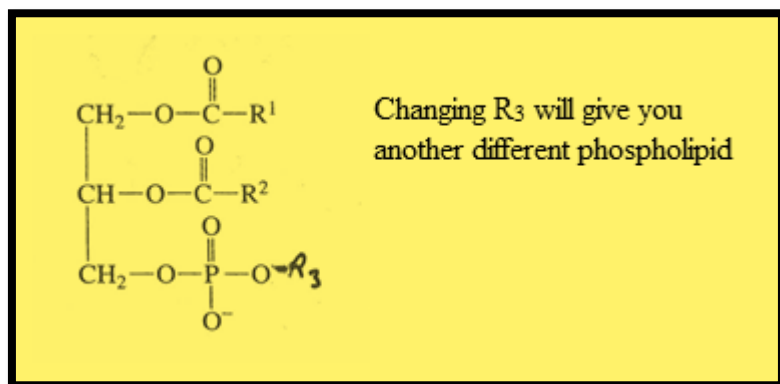
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Palmitic (64 °C) > Oleic (16 °C) > Arachidonic (-49 °C)

A saturated fat is more likely to clog an artery. Diets high in meats mean there are more saturated fats. A double bond puts a so-called “kink” into the molecule and will prevent tight packing. This will lower the interaction between the molecules (think Van der Waals), hence as the amount of unsaturation increases, so does the fluidity. The melting point will be lower.

2. **Phospholipids:** which are in the cell membrane look like this:



I will show you a few examples that I present to my students. I hope you enjoy them and will learn from them.

Example 1:

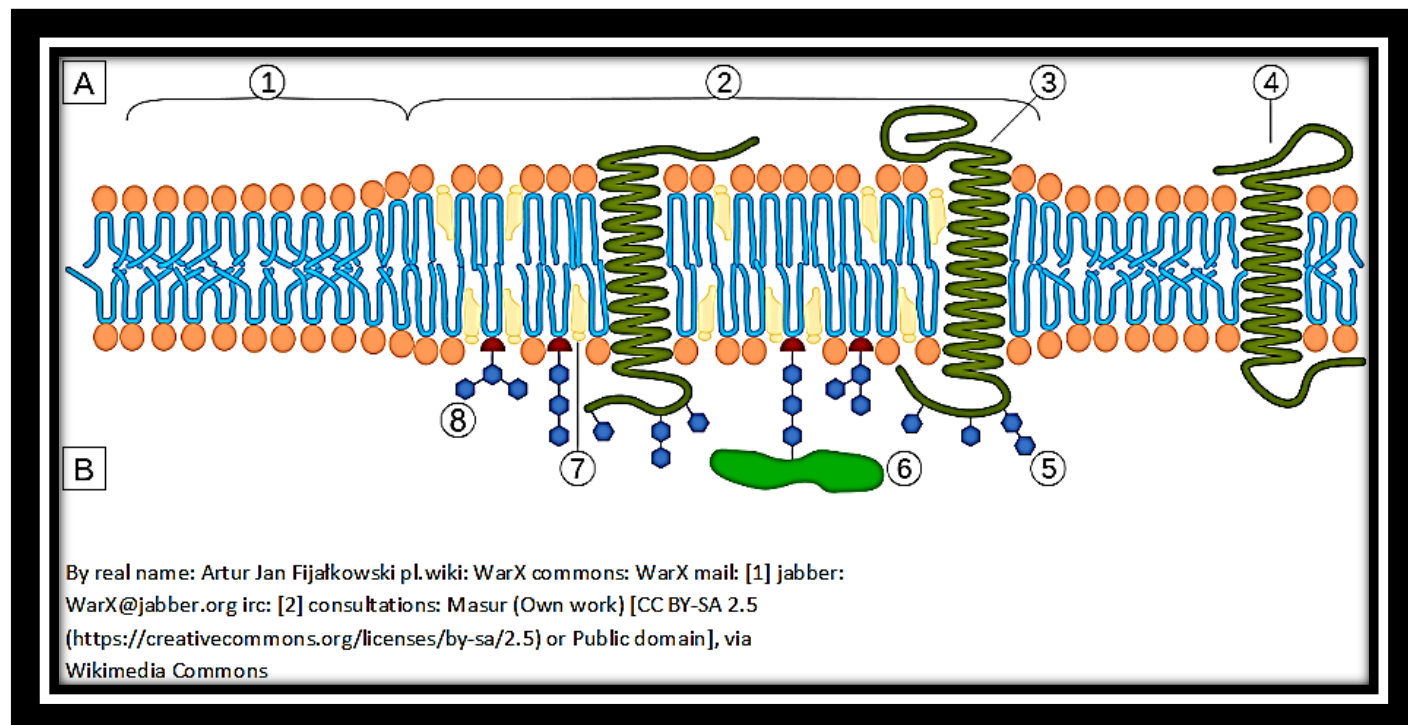
Membrane compositions of fish and other cold-blooded animals change when their environmental temperature is lowered. The unsaturated fatty acid content of the lipids in the cell membranes increases when the organism becomes adapted to the lower temperature. What is the purpose of this adaptation?

It is essential to survival that a membrane be flexible and relatively fluid-like. By increasing the percentage of unsaturated fat in the membrane we maintain flexibility and prevent it from becoming rigid.

We also see this adaptation in bacteria.

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If a bacteria lived in a hot spring, we'd expect to see an increase in percentage of saturated fat. By increasing the amount of saturated fatty acids, we will prevent the bacterial membrane from melting!!



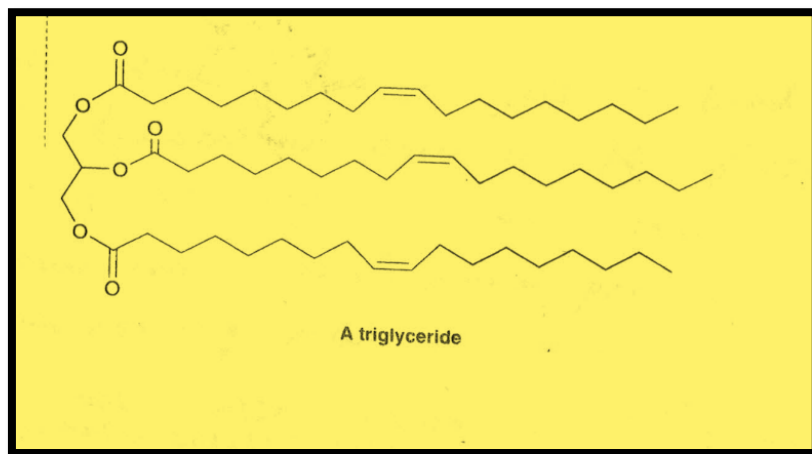
Bottom Line:

If too hot: increase percentage of saturated fatty acids

If too cold: increase percentage of unsaturated fatty acids

Example 2:

Consider the below triglyceride:



a) Why do we hydrogenate this?

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To convert the liquid molecule into a semi-solid!

b) Why do we do this, isn't this bad?

LOL... money!!... Adding the H_2 makes for a nicer appearance and a longer shelf-life!

c) Why does partial hydrogenation produce “bad” fats?

Catalysts present during the hydrogenation can often isomerize the cis-double bonds into trans double bonds... these so-called trans-fats cause an increase in LDL cholesterol!!

Example 3:

Stearic acid has a melting point of $69.6^{\circ}C$ while oleic acid has a melting point of $16.0^{\circ}C$. Both compounds have the same number of carbon atoms. Explain.

Oleic acid has a cis bond which prevents the hydrocarbon chain of the fatty acids from packing as tightly as that of the saturated stearic acid. This looser packing is reflected in a lower melting point.

Example 4:

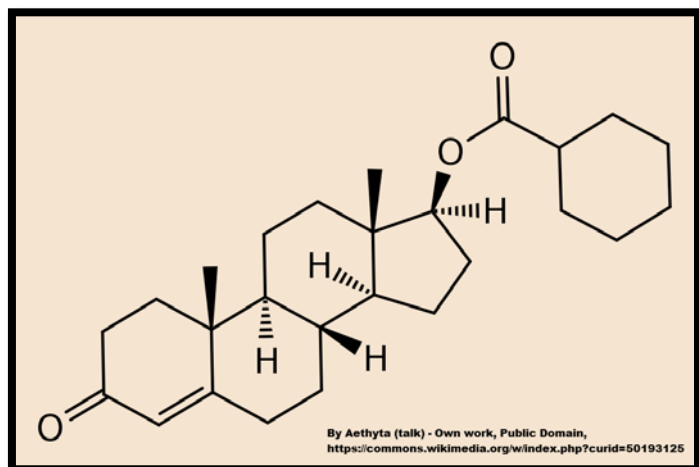
E. coli cells cultured at $10^{\circ}C$ have a ratio of unsaturated: saturated fatty acids of 2.9. The same bacterium cultured at $40^{\circ}C$ has a ratio of .38.

Bacterial cells must maintain a certain membrane fluidity to function optimally. The culture at $10^{\circ}C$ must have more unsaturated fatty acids since the unsaturated chains have a lower melting temperature, and therefore a higher fluidity. Those cultured at higher temperature achieve the same fluidity by increasing the amount of saturation.

Example 5:

What structural features distinguish between steroids and prostaglandins? What is the major difference in biological functions between steroids and prostaglandins?

A steroid has three six-membered rings and one five-membered ring as shown:



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Prostaglandins are derived from the 20C Arachidonic acid.

These steroids make up such things as estrogen, cholesterol, progesterone, and testosterone!

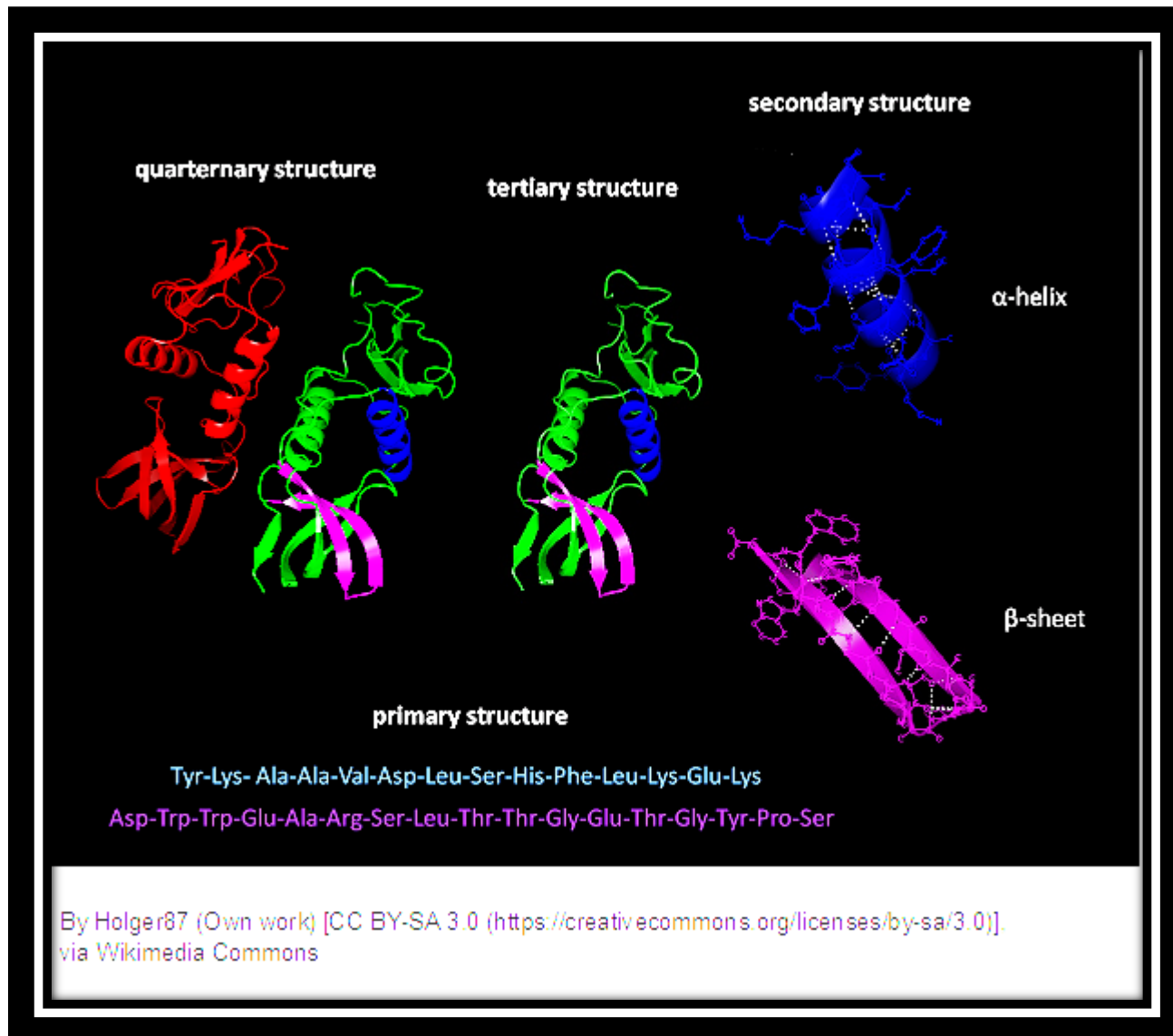
Cholesterol is an unsaturated steroid alcohol which makes up a significant part of membranes. The prostaglandins are like hormones, but work locally in nearby cells. Actually, they work together with hormones. In some organs they:

- 1) Help regulate blood flow
- 2) Effect nerve transmission

★ Some prostaglandins enhance inflammation. Aspirin can inhibit the work of an enzyme needed in the synthesis of prostaglandins.

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Proteins



Lipids and carbohydrates usually only contain C, H, N, O... but proteins contain C, H, N, O, S.

This is important to know for the DAT! Thus, if you radio-label a S atom, it is likely to end up in a protein. Proteins have the widest array of functions which include:

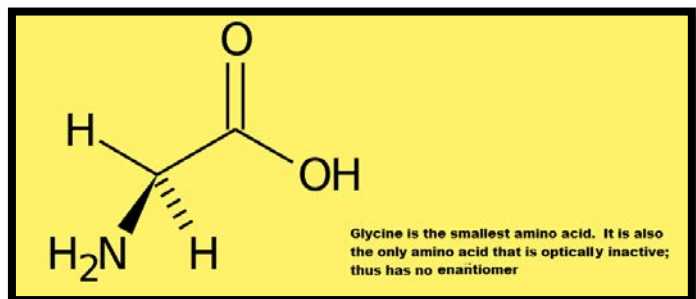
- Enzymes:** these are the biological catalysts that will lower the energy of activation, thus speeding up many reactions.
- Hormones:** many, but not all hormones are protein-derived. Insulin is a hormonal protein.
- Protective:** antibodies (immunoglobins) are proteins and are linked by disulfide -S-S- bonds
- Storage:** e.g. casein is the protein of milk represents the major amino source for young mammals
- Receptors:** on cells, and responsible for detecting chemical signals
- Transport:** hemoglobin is an example of a globular protein that transports O₂

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- g) **Structure:** collagen, keratin, and elastin are fibrous proteins contributing to the structural integrity of the organism.
- h) **Motor Movement:** Dynein is a “motor protein”, actin and myosin are also proteins

Proteins are made up of individual units called **amino acids**.

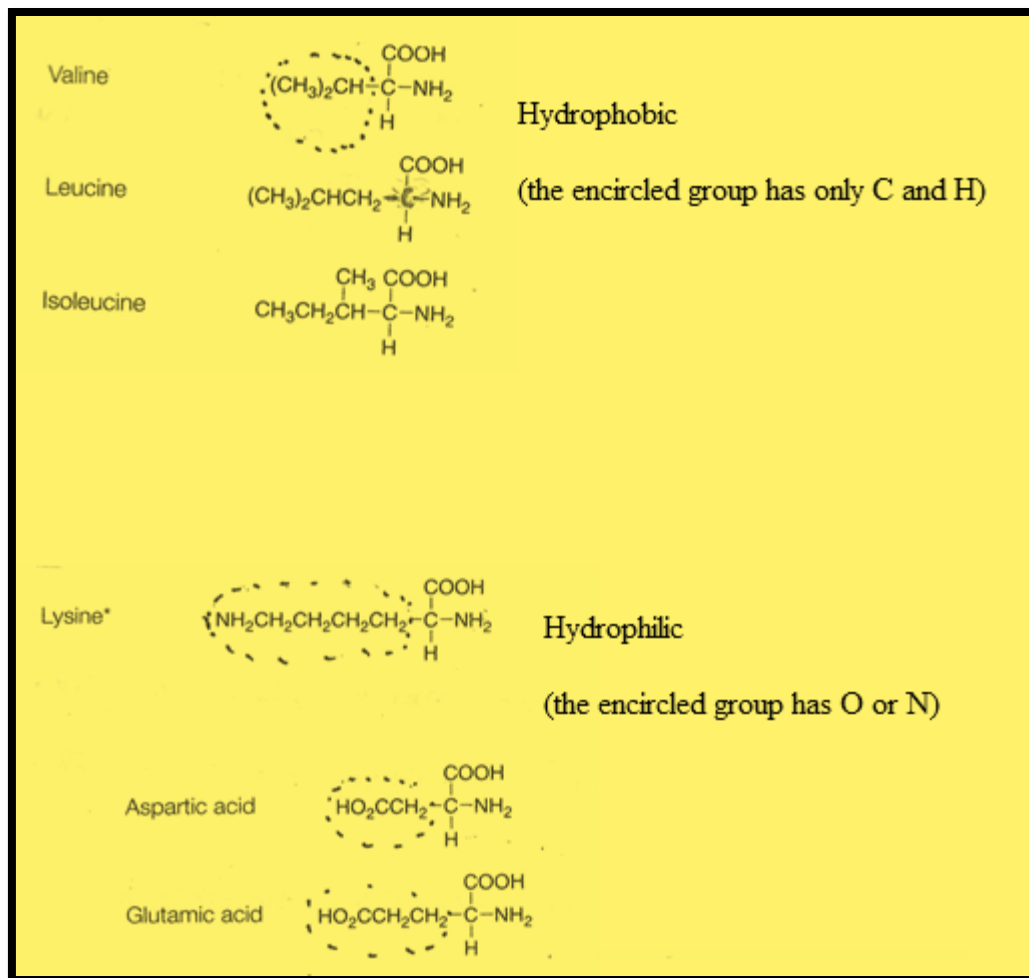
Let's see a few:



Some amino acids are H₂O soluble (Hydrophilic)

Some amino acids are H₂O insoluble (Hydrophobic)

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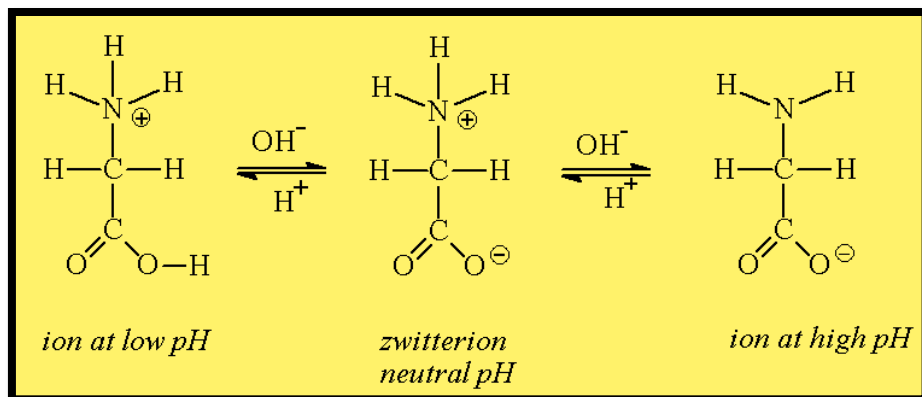
★ **For the DAT exam, simply be able to tell if a given amino acid is hydrophilic or hydrophobic. No need to memorize.**

Essential amino acids must be obtained from the diet.

Amino acids do not exist to an appreciable extent as uncharged molecules. They exist as salts... allowing them to have high melting points and be water soluble.

Let us examine:

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The COOH and NH_3^+ groups are ionizable; they can lose an H^+ in solution. **The DAT Destroyer will do specific problems on this in the organic chemistry section.**

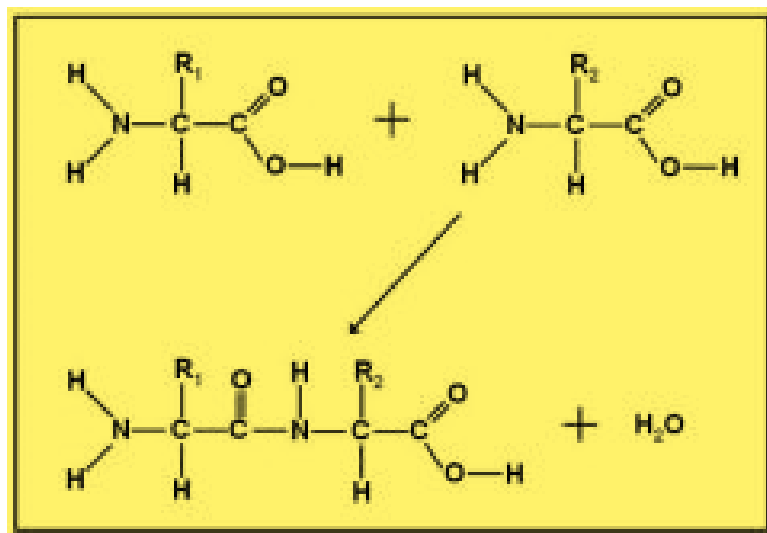
Note:

In a highly **acidic** environment we see $^+\text{NH}_3$ and COOH

In a highly **basic** environment we see NH_2 and COO^-

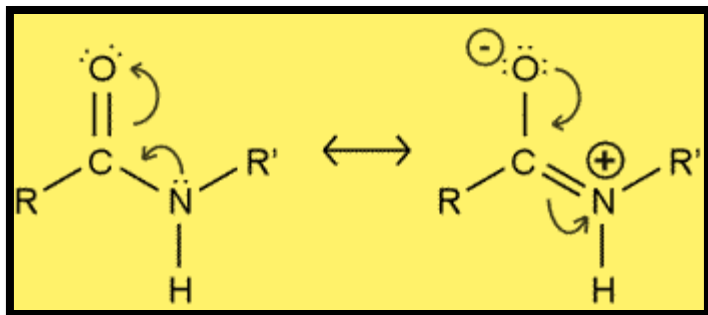
At physiological pH, we see the neutral form, $^+\text{NH}_3$ and COO^- , and we call it a **Zwitterion**.

Now... amino acids can link together to form a peptide bond as water is removed. For example, consider the following:



I boxed off the peptide bond for you. Let us now focus on it.

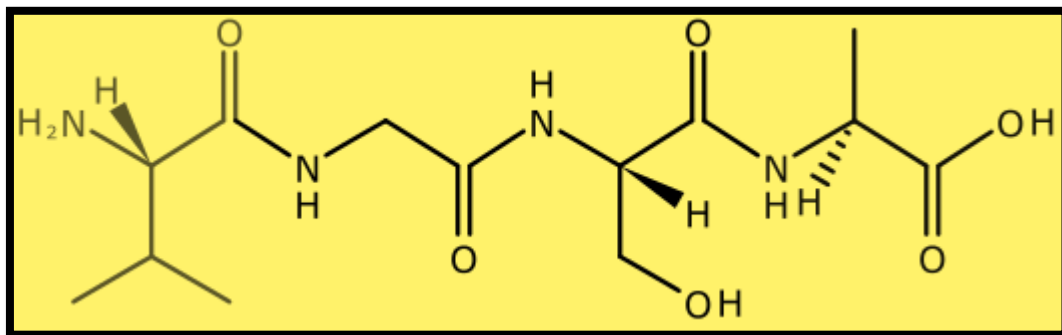
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Because of resonance, a peptide bond has about 40% of double bond character. It is rigid, not allowing free rotation. We see a flat sp^2 structure. **Steric Hinderance** causes the trans conformation to be more stable than the cis conformation.

Very important DAT concept: Very little free rotation!!

Here is a segment of a polypeptide chain. Notice the R groups alternate!!



Recall, man uses the D-sugars. Proteins use the L-amino acids. All L-amino acids have the S-configuration except for cysteine... our sulfur-containing amino acid.

20 naturally occurring amino acids exist. Don't worry about any specific structures.

Often, we use abbreviations for the amino acids. For example, Glycine is Gly, Phenylalanine is Phe, and Cysteine is Cys. Let me show you two really cool problems:

Problem 1:

How many structural isomers would there be for Val·Ala·Tyr?

$$3! = 3 \times 2 \times 1 = 6$$

Val·Ala·Tyr	Ala·Tyr·Val
Val·Tyr·Ala	Tyr·Ala·Val
Ala·Val·Tyr	Tyr·Val·Ala

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Problem 2:

How many optical isomers?

$N = 3$ since each is chiral.

$$2^3 = 8$$

D-Val·D-Ala·D-Tyr

L-Val·L-Ala·L-Tyr

D-Val·D-Ala·L-Tyr

D-Val·L-Ala·D-Tyr

D-Val·L-Ala·L-Tyr

L-Val·L-Ala·D-Tyr

L-Val·D-Ala·L-Tyr

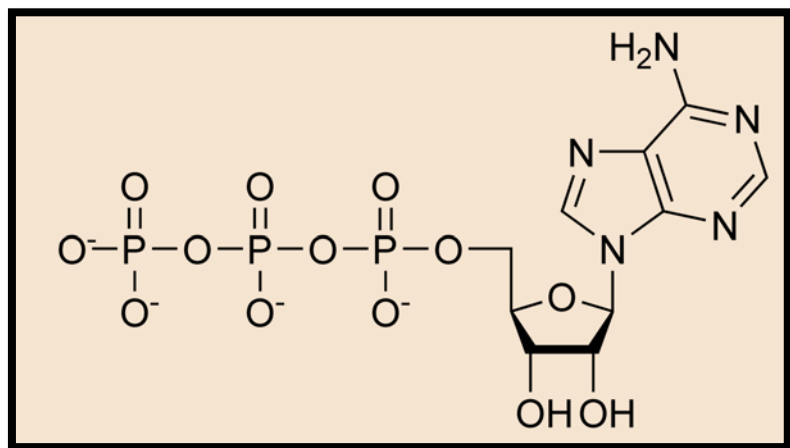
L-Val·D-Ala·D-Tyr

Which is most likely to be found in nature?

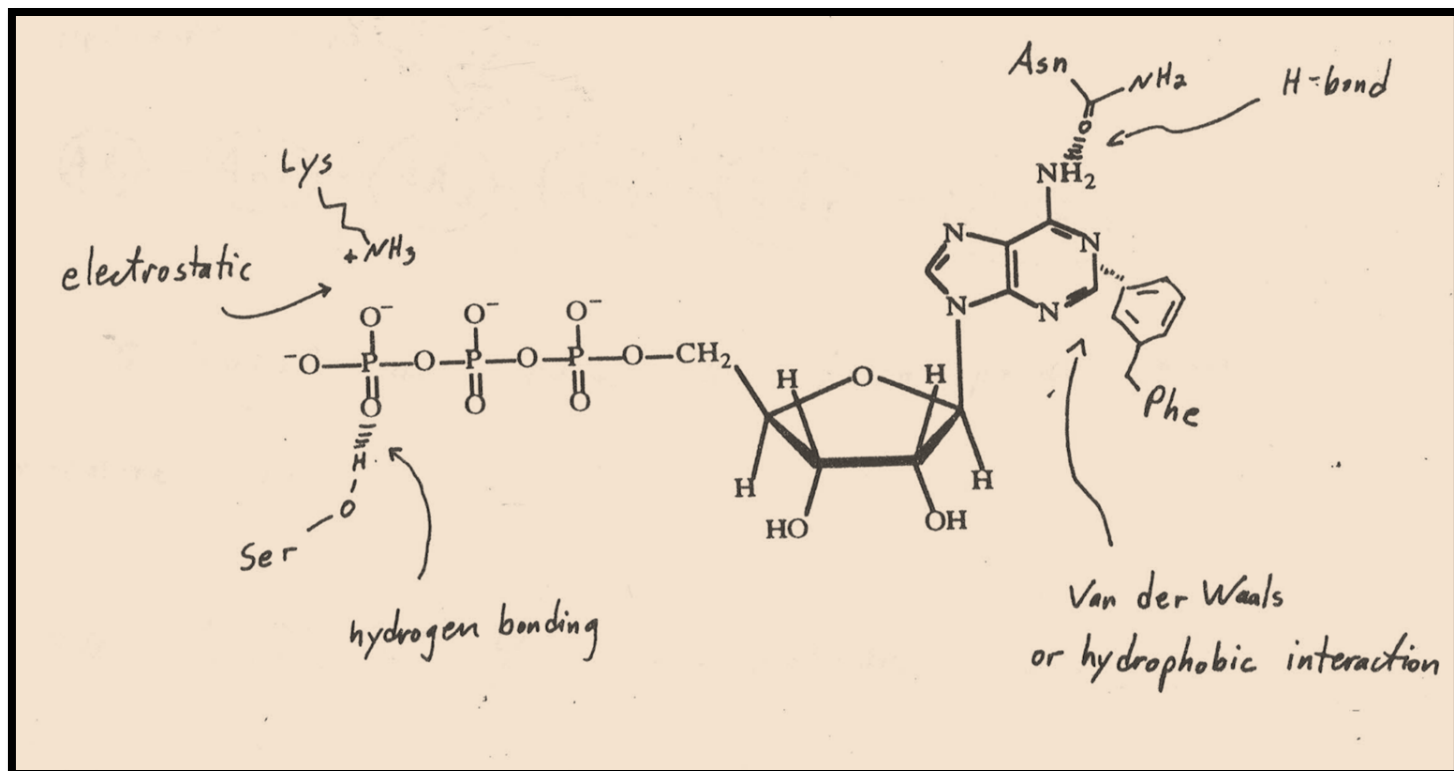
Some amino acids can bind ATP in an enzyme active site. Interactions could include:

- a) Electrostatic
- b) Hydrogen bonding
- c) Van der Waals (Hydrophobic Interaction)

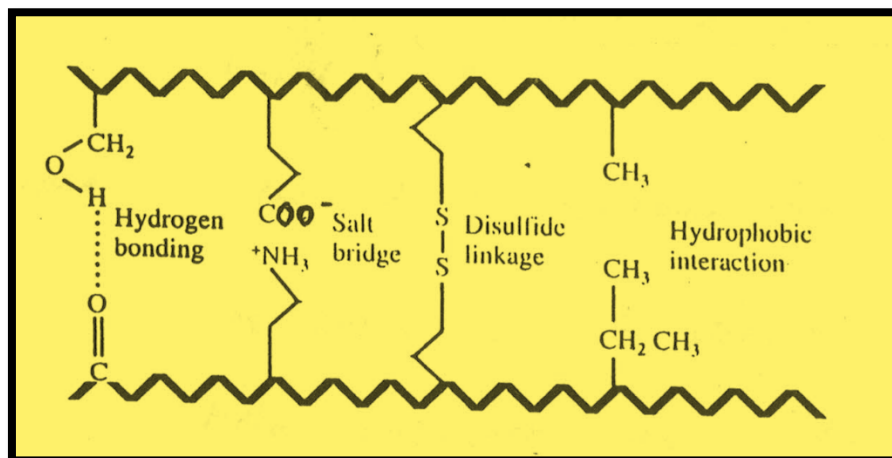
Have a look:



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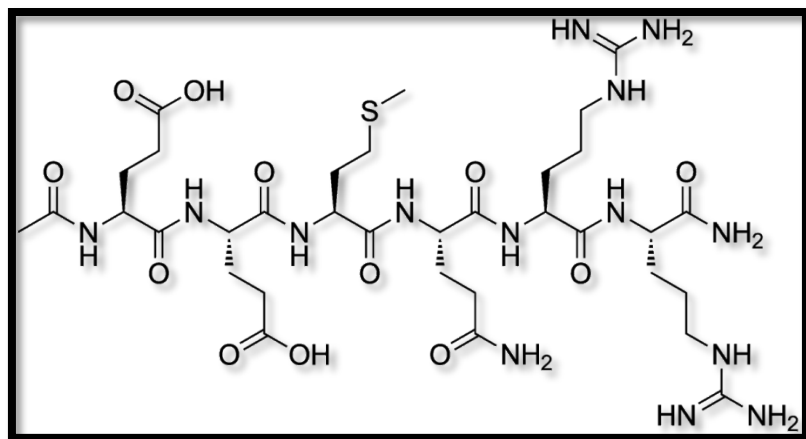


In a protein, several attractive forces or bonds can be found:



If a peptide had six amino acids, we have five peptide bonds.

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5 “cuts” take this hexapeptide and hydrolyze it.

The 1°, 2°, 3°, 4° structures are important to understand.

1° structure: sequence of amino acids, held by covalent bonds including the disulfide bond

2° structure: the 3D conformation of localized regions (e.g. helix or β -pleated sheet held together by hydrogen bonds)

3° structure: the 3D shape of the entire molecule held together by hydrogen bonds, disulfide bonds, salt bridges (electrostatic interactions), and Van der Waals (hydrophobic interactions).

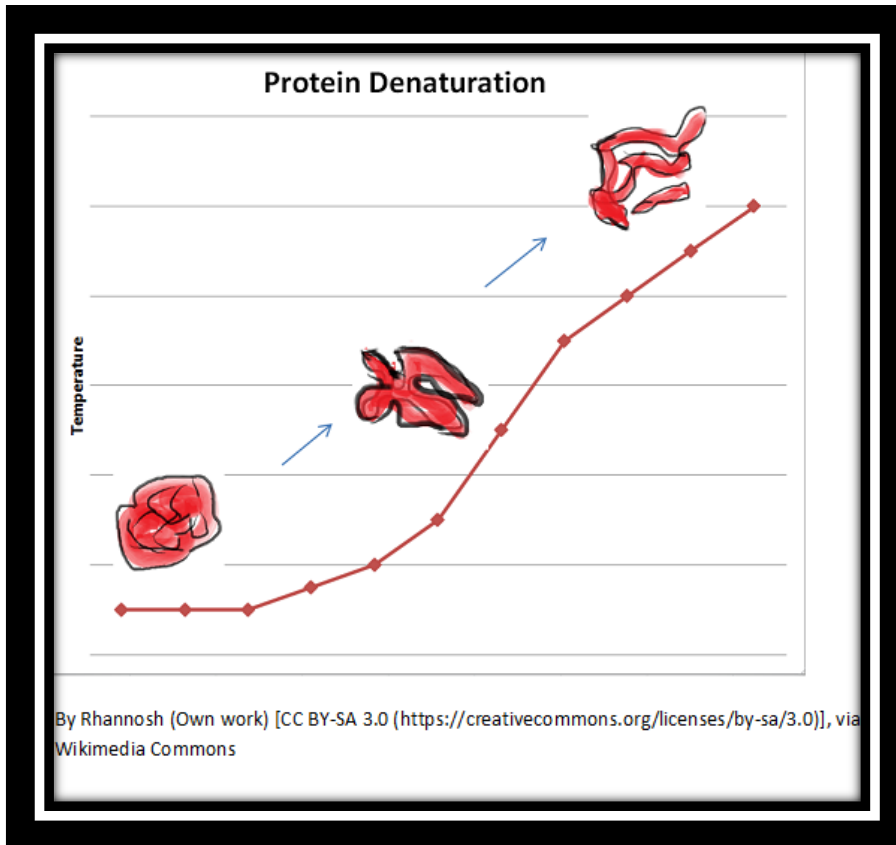
4° structure: Refers to the way one polypeptide chain interacts with another. (e.g. the two alpha chains of hemoglobin interact with the two beta chains.) The same four attractions as the 3° are seen in the 4° structure.

What is the difference between digestion and denaturation?

Digestion is simply the breaking of the amide (or peptide bond), we lose the 1° structure.

In denaturation, the 1° structure is not changed, but we lose 2°, 3°, and 4° structures.

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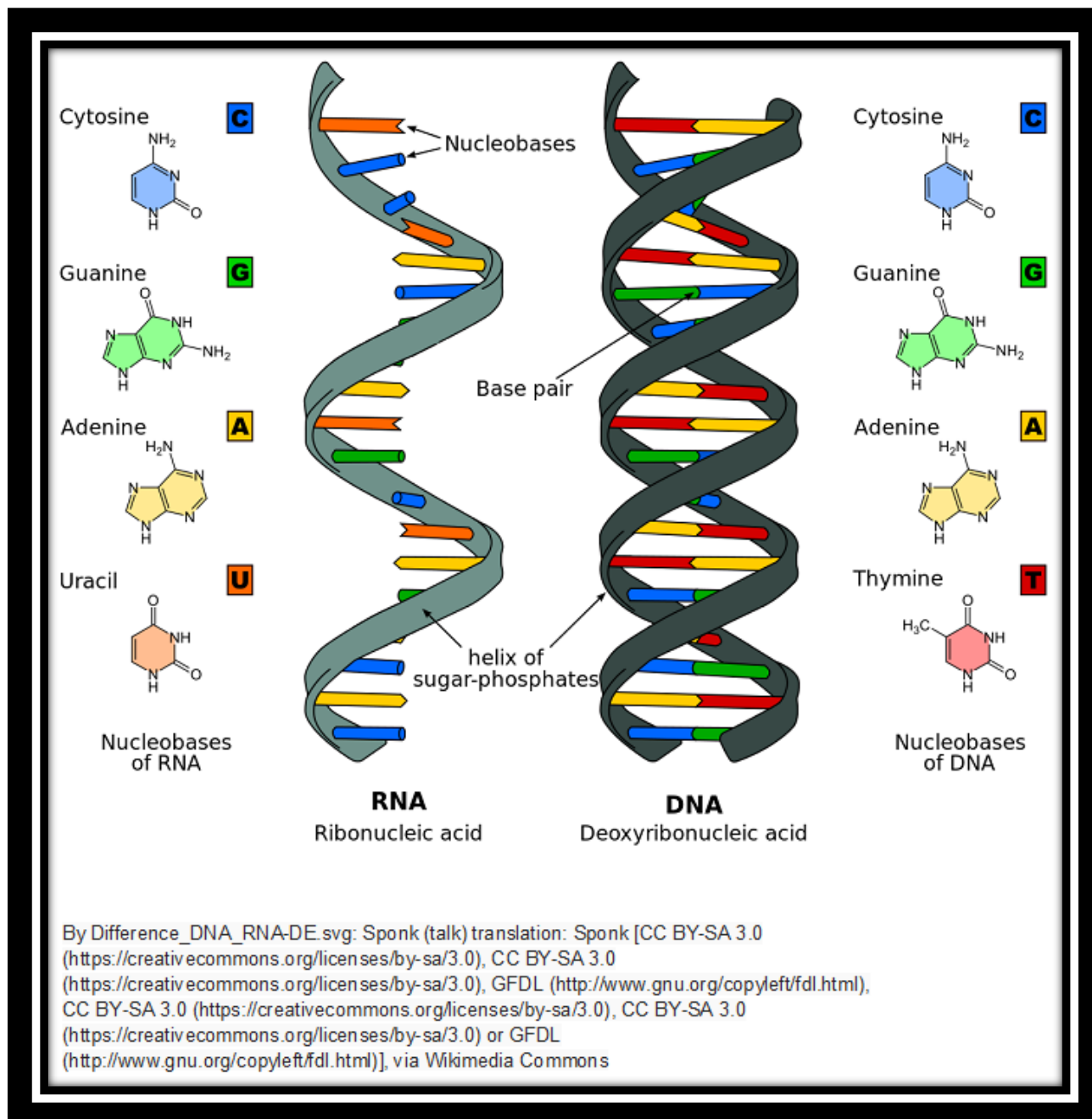


Denaturing agents include:

- a) Heat: disrupts H-bonds... causes molecules to vibrate too violently. (e.g. cook an egg)
- b) Radiation works in the same/similar way as heat
- c) Detergents: affects salt bridges and H-bonds
- d) Strong acids/bases: same as detergents
- e) Salts of heavy metals, such as Ag^+ , Hg^{++} , Pb^{++} combines with SH groups and forms precipitate, as well as acidic amino acids
- f) Urea: disrupts H-bonds

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Nucleic Acids



These are chemical carriers of genetic information.

They include **DNA** and **RNA**

DNA forms a **double** helix; RNA consists of a **single polynucleotide chain**.

DNA is found in the nucleus, as well as the mitochondria and chloroplast in plants. DNA is gigantic, the molecular weight can approach 50 billion!! Each gene is a part of a DNA molecule.

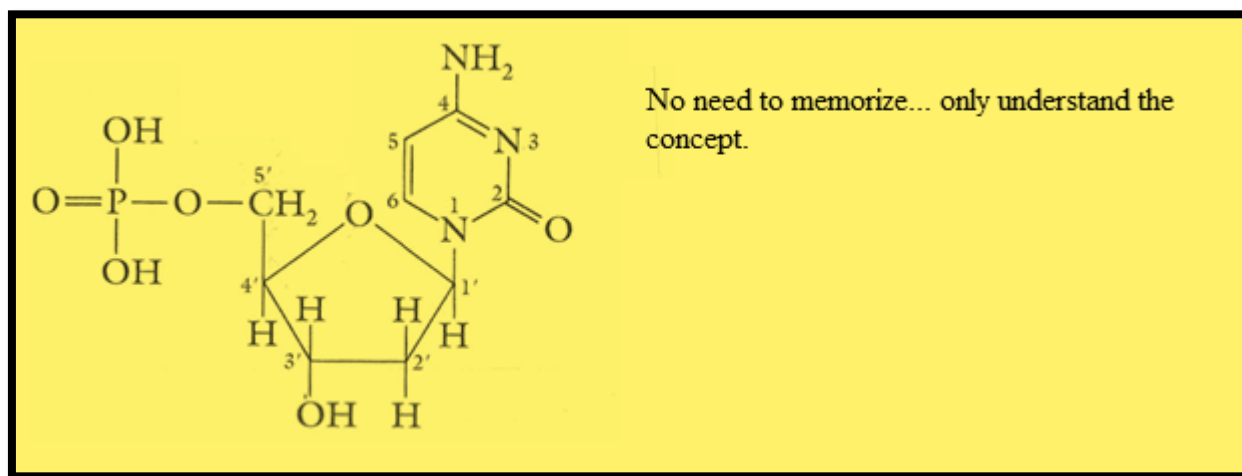
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RNA molecules will leave the cell nucleus and direct the synthesis of proteins in ribosomes.

Nucleic acids are also polymers, the same way as polypeptides and carbohydrates, the monomers of nucleic acids are called **nucleotides**. A nucleotide is hydrolysable into three components:

- a) Sugar
- b) Phosphate
- c) N-base (heterocyclic nitrogen base)

Let us look at the structure:

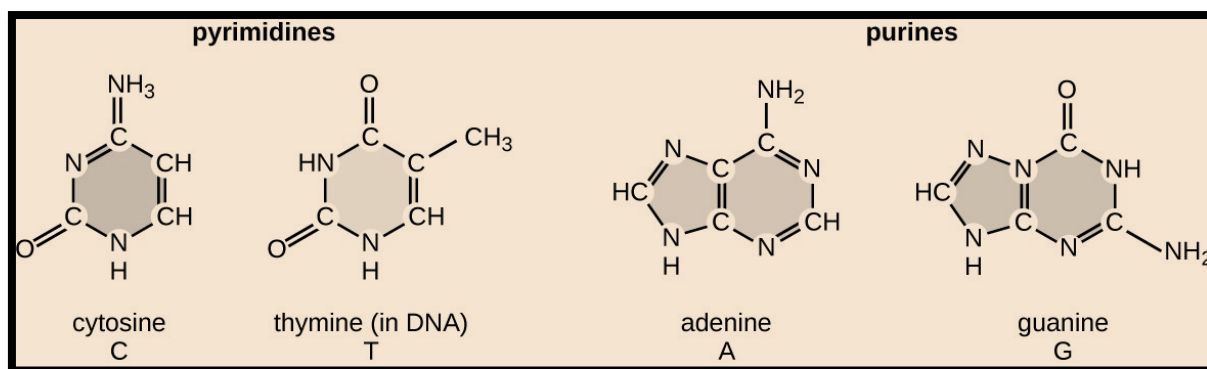


If you notice... the sugar portion lacks a 2' OH group... this is a deoxy sugar.

Ribose sugar is in RNA; 2-deoxyribose sugar is in DNA.

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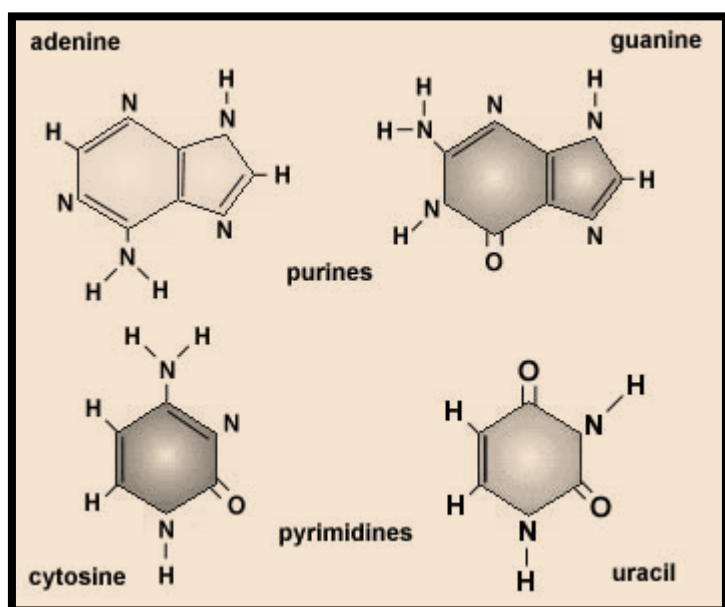
DNA has 4 N-bases: Here they are...



Recall, **A=T two H-bonds**

C≡G three H-bonds

RNA has A, C, G, U



C≡G but A=U

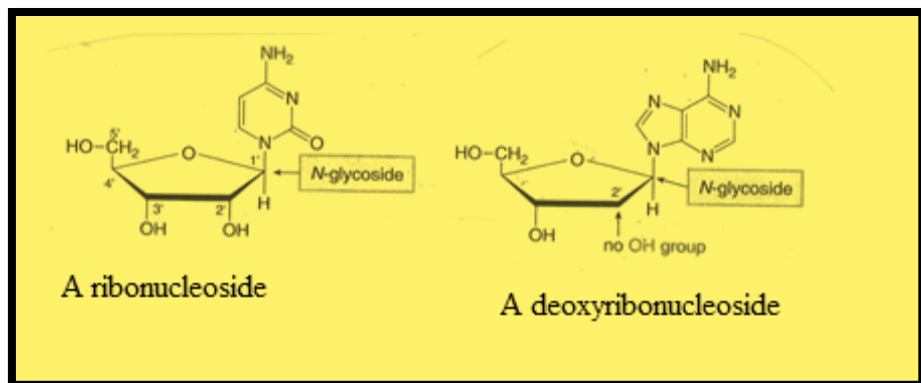
Purines: A and G... 2 rings

Pyrimidines: C, U, T... 1 ring

I will go into more details on this later in these notes.

A **nucleoside** = sugar and N-base.

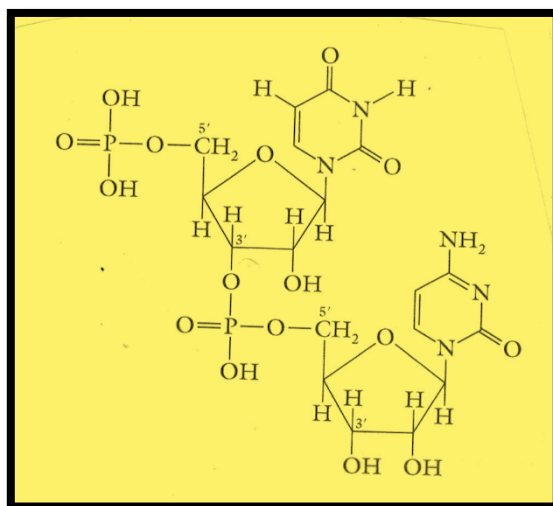
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★ The sugar-phosphate “backbone” forms the structural framework of DNA and RNA (**Know that for the DAT, you will thank me!**) 😊

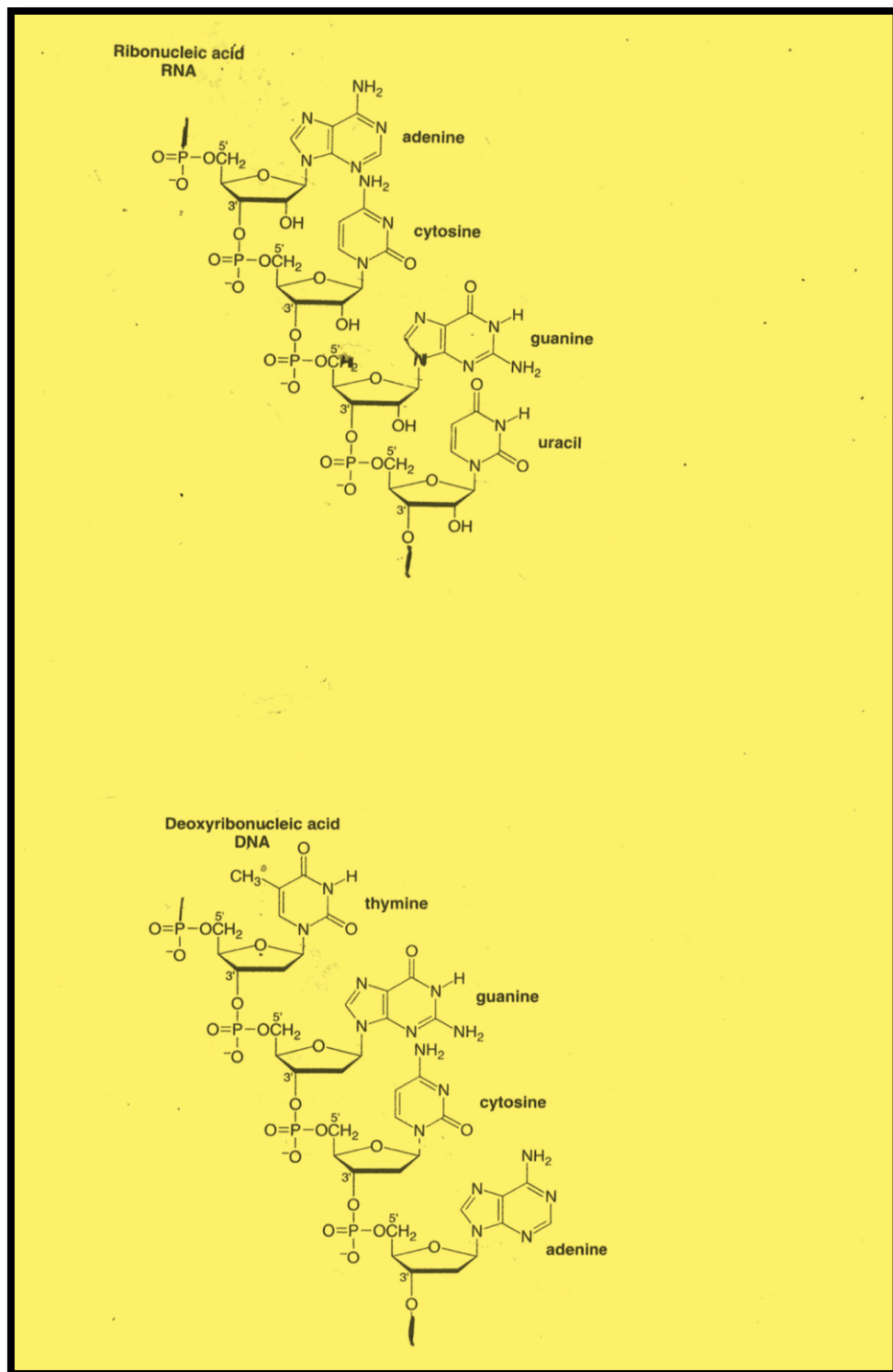
Before we look at an RNA and DNA, I want to make sure you understand what a **phosphodiester** group is. Notice below at how it joins the 3' of one sugar with the 5' of the other.

For the DAT, make sure that you simply understand that the connection between successive monomer units



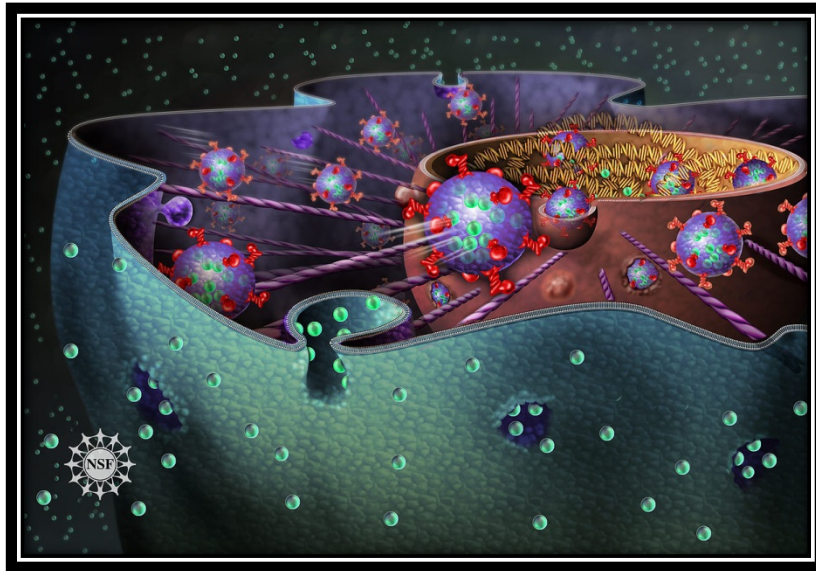
in nucleic acids is this **phosphodiester link**. It is between the 3' OH group of one sugar and the 5' OH of another sugar.

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Chapter 2 - Cells

Cells



The basic functional units of complex organisms are cells. Within cells, we find metabolically active structures that are involved in performing many functions. These structures are called **organelles**.

Let me first define a few terms for you...

Protoplasm is the living substance of the cell and includes:

- a) Cytoplasm
- b) Karyoplasm

The **karyoplasm** simply forms the contents of the nucleus.

The **cytoplasm** involves the contents of the cell excluding the nucleus.

The **plasma membrane** (plasmalemma) separates the cytoplasm from its extracellular environment.

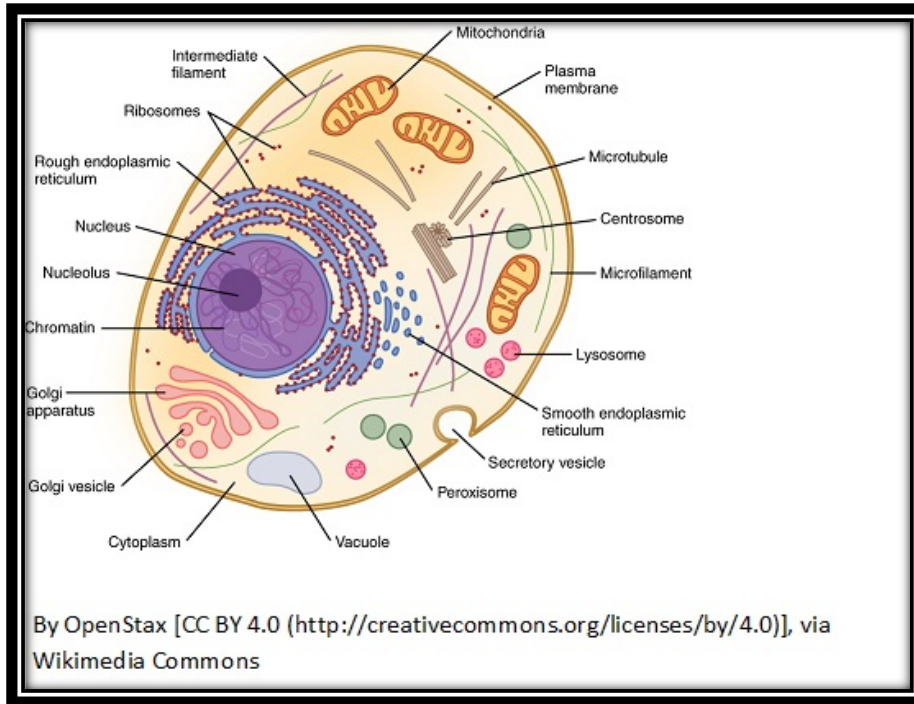
Cytoplasm is mainly H_2O , and various organic and inorganic substances are dissolved or even suspended. The fluid suspension is the **cytosol**.

Cells have shape, can move and have the ability to communicate. A system of tubules and filaments comprise the **cytoskeleton**. The cell organelles can be membranous such as the mitochondria or lysosome, or be non-membranous such as the ribosomes.

Let us examine some cellular organelles that you need to know for the DAT. Once you are done with these notes, hit the DAT Destroyer hard. My group has consistently “kicked ass” in this Biology section for the past 25 years. These notes hold the key for you. Study them, add to them, put in your own additional comments... this is your masterpiece... I want you to own it.

Cellular Organelles

Chapter 2 - Cells



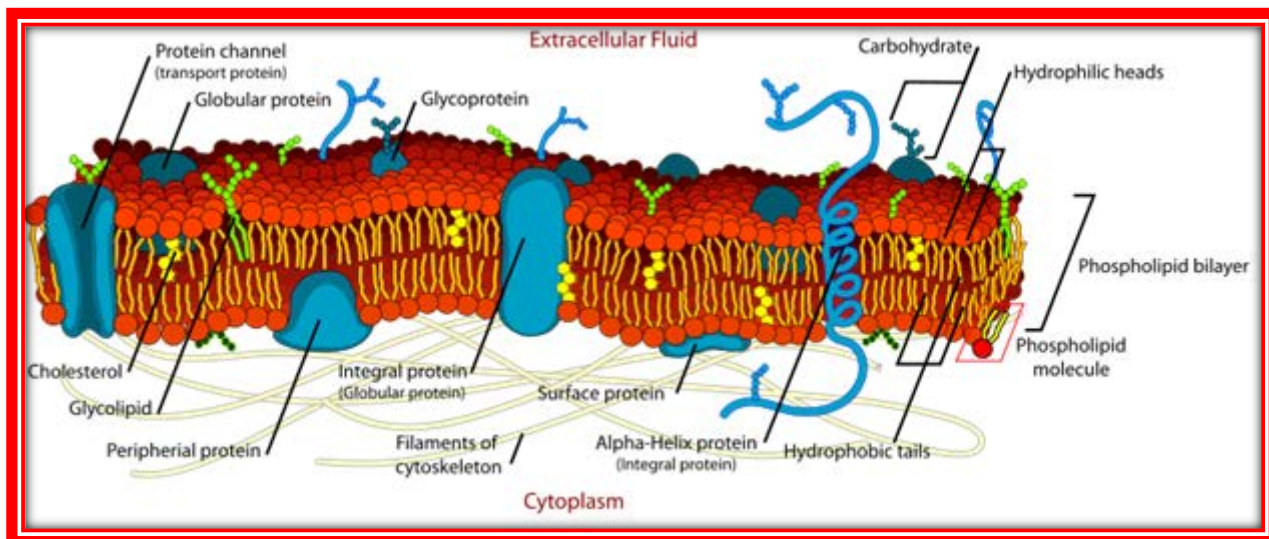
Plasma Membrane (Plasmalemma)

Allows the cell to maintain homeostasis (steady state of equilibrium).

Allows ions and other solutes to be transported in or out and contains ion channels and many proteins.

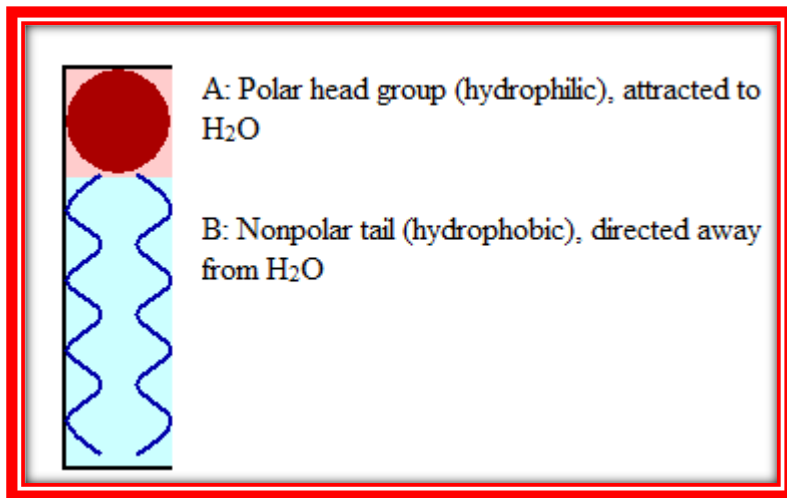
This plasma or cell membrane contains phospholipids, cholesterol, proteins, glycoproteins. This selective barrier regulates materials from passing into or out of the cell.

Let us have a look:



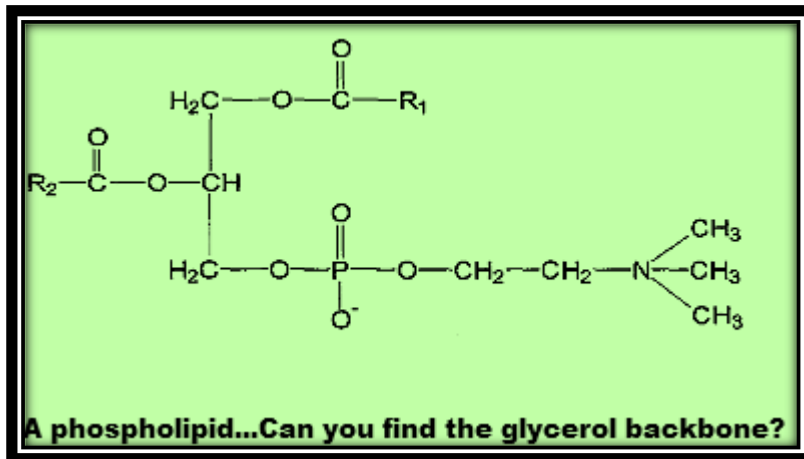
Chapter 2 - Cells

Membrane phospholipids are most stable when organized in a **lipid bilayer** as shown:



As you can see, each phospholipid molecule of the lipid bilayer is made up of this polar head group and two long nonpolar fatty acyl tails projecting inward.

The phospholipid is composed of both a hydrophilic area and a hydrophobic area. Therefore, the molecule is **amphipathic**.

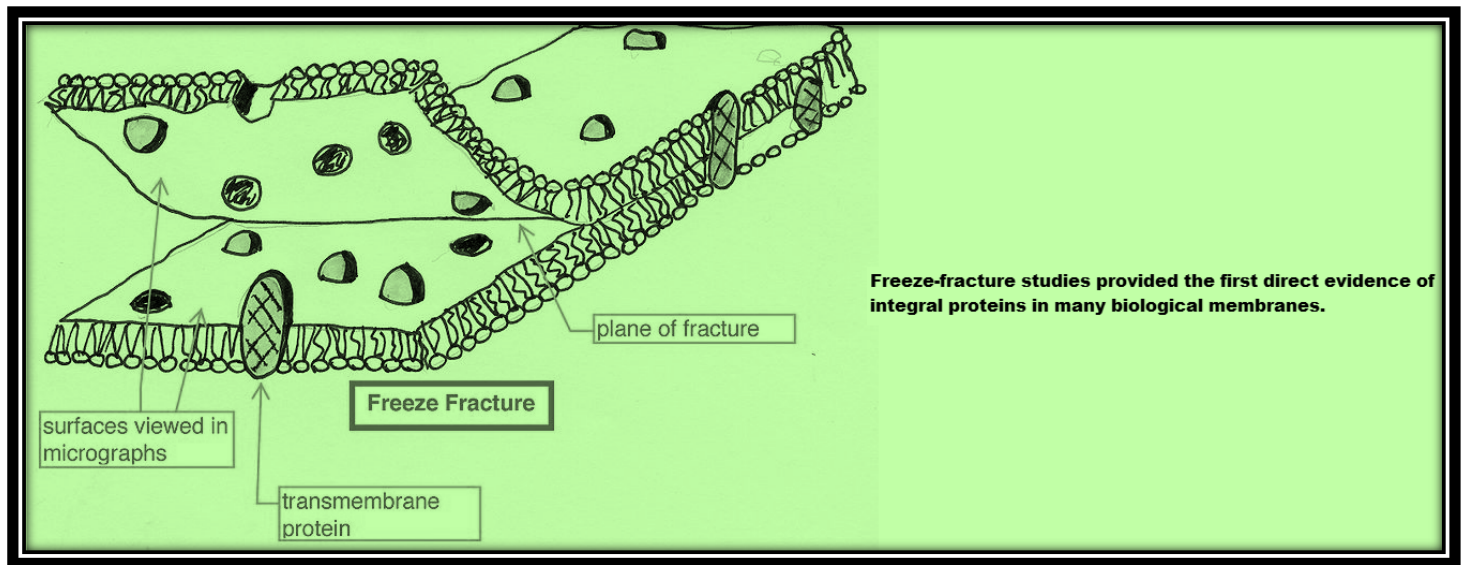


Hopefully, you can see that the protein components can span the entire length (**integral**) or are simply attached to the cytosolic side (**peripheral**). Since most integral proteins span the entire length, we refer to them often as **transmembrane proteins**. These transmembrane proteins are often quite long and can fold while forming channels that allow the passage of specific ions or molecules.

These proteins can float in this bilayer sea much like an iceberg. This model is called the **Fluid Mosaic Model**. Proteins literally float in a lateral motion along the plane of the membrane. ★ Lipids and many membrane proteins are in constant lateral motion.

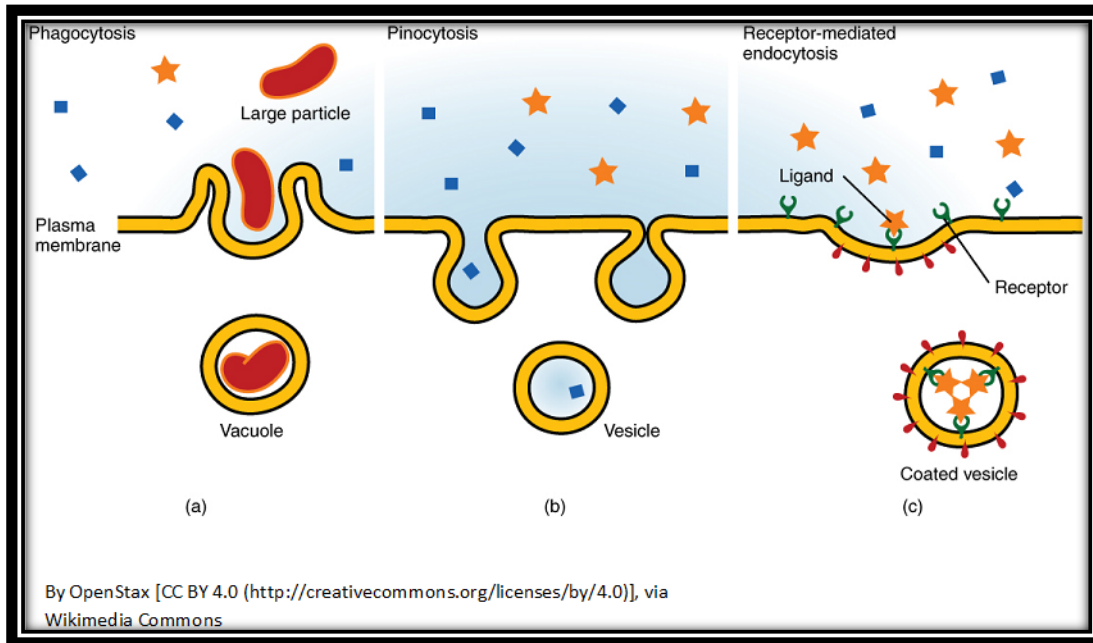
In a technique called freeze-fracture, we can study the bilayer. The interior and exterior are surely not symmetrical.

Chapter 2 - Cells



Chapter 2 - Cells

Endocytosis and Exocytosis



Let us examine exocytosis and endocytosis.

In **endocytosis** we see uptake of a molecule and produce a new vesicle from the plasma membrane.

Three types of endocytosis: All require ATP

Phagocytosis: cell eating... such as the engulfing of microorganisms, cellular debris, old, worn-out cells (e.g. macrophages and neutrophils).

Pinocytosis: cell drinking... the cell takes in droplets of extracellular fluid which contains the solute molecules

Cell-Mediated Endocytosis: Here we see the capture of macromolecules using receptor proteins in the cell membrane. These receptor molecules associate with the macromolecule and then become associated intracellularly as well using a molecule called **clathrin**. Hormones, growth factors, antibodies, even antigens are bound at the cell surface. A region of the cell membrane called a **coated pit** is lined by a layer of proteins. Upon binding, the coated pit forms a vesicle!! You need not know any details, but clathrin is a major player in cell-mediated endocytosis. For those who are interested, YouTube has some amazing video clips that show clathrin at work. By far, the coolest looking molecule I have ever seen!!

Exocytosis... requires ATP

Molecules are secreted by the fusion of vesicle with the plasma membrane. The release of the contents goes to the extracellular space without compromising cell membrane (plasma membrane) integrity. Beta cells of the pancreas make insulin and secrete it into the blood by exocytosis. (Exocytosis is triggered in many cells by a brief release of Ca^{++} ions in the cytosol). Neurotransmitters released into the synaptic cleft is done by exocytosis.

Chapter 2 - Cells

Glycocalyx

In a transmission electron microscope study, we would see the external of the cell showing a “fuzzy” area. This is the glycocalyx. It essentially is the carbohydrate chains covalently linked to the transmembrane proteins and/or phospholipids on the outer portion.

It has many negatively charged sulfate and carboxyl groups. They are involved with making up receptors that participate in functions such as cell recognition, hormone response, and adhesion.

Thus, as you can see, the plasma membrane has four main functions:

- A) **Physical barrier**: partitions substances on the inside vs. outside
- B) **Cell Communication**: think receptors!!
- C) **Selective Structure**: regulates ion and molecule flow
- D) **Protection and Support**: maintains cell integrity

Mitochondria



This is a 2D picture, thus it was taken with a TEM (transmission electron microscope). Note the cristae... foldings of the inner membrane, which greatly increases the surface area.

Powerhouse of the cell

Contains enzymes specialized in **making ATP** and carrying out **aerobic respiration**

Can have a shape that is round or elongated

Cells usually possess a high number, but kidney and heart have enormous numbers of mitochondria!!

Heart has the most; kidneys are second for those who are curious.

A liver cell might have 2,000, but a heart cell has 5,000 mitochondria.

Animals and plants contain mitochondria.

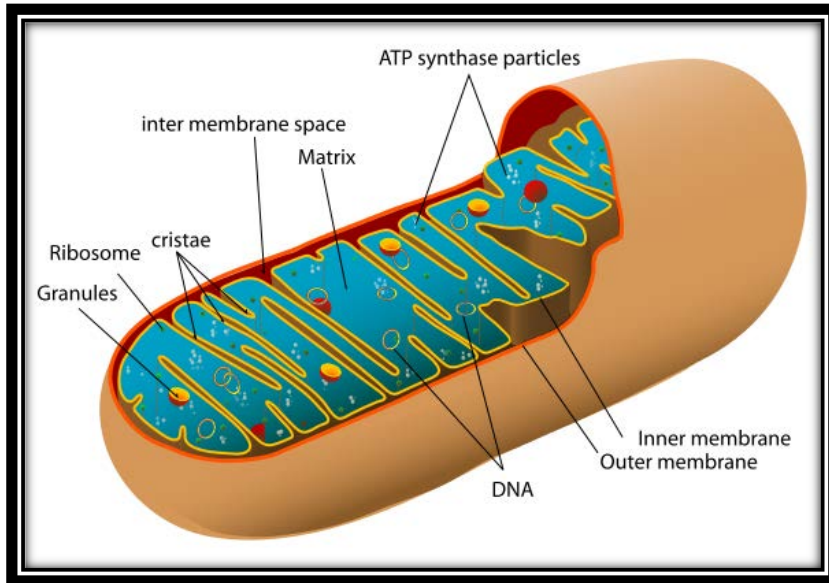
Chapter 2 - Cells

Often can be visible with a light microscope.

The **outer membrane** allows the passage of small molecules and ions. The **inner membrane** is highly folded and is a closed space, even to small ions!

The **inner mitochondrial membrane** is where the electron transport chain that makes up almost 90% of the ATP is found.

The **matrix** of the mitochondria is enclosed by the inner membrane. This might sound a bit confusing, but let's have a look:



Matrix: Krebs Cycle (TCA cycle) and Fatty Acid Oxidative processes occur... contains many enzymes, ribosomes, and mitochondrial DNA. Very gel-like and viscous.

Inner membrane: Electron Transport Chain

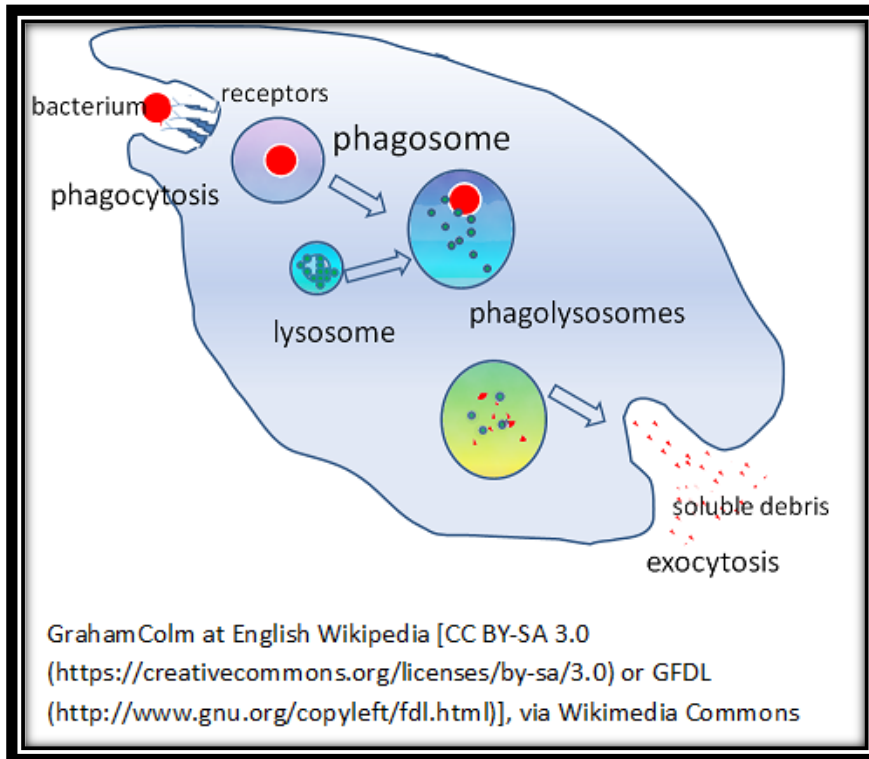
Although most DNA is packaged in chromosomes, mitochondria have a small amount of their own DNA.

Mitochondrial DNA is double-stranded, but circular. This has led scientists to believe that mitochondria originated from an ancestral aerobic prokaryotic bacterium ... This bacterium adapted to a symbiotic relationship with an ancestral host cell. This is the **Endosymbiotic Theory**. Mitochondria are self-replicating too, with an average life span of about 10 days.

Oxidative damage to the mitochondria has been proposed to play a role in the aging process.

Chapter 2 - Cells

Lysosomes



Membrane bound organelle that contains hydrolytic enzymes used to digest macromolecules.

Over 40 different enzymes are found and are particularly abundant in cells with high phagocytic activity.

Phagocytosis is a type of endocytosis in which large particles are engulfed or eaten by the cell. **Neutrophils**

and **macrophages** are loaded with lysosomes. (Know this for the DAT, you may one day thank me 😊).

★ I know that the Campbell book says that plants lack lysosomes. I disagree, and refer you to Google British Society for Cell Biology and see some new data!!

pH is about 5 within lysosomal lumen.

Usually spherical in shape.

Lysosomes will digest:

- a) Microorganisms like fungi or bacteria
- b) Cellular debris such as old cells
- c) Old organelles such as mitochondria

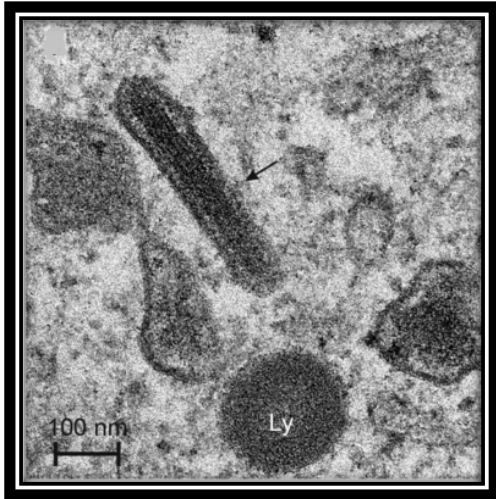
Enzymes include proteases, nucleases, phosphatases, sulfatases, etc.

Thus, I hope you can see... not many macromolecules escape.

Any leaked lysosomes are normally harmless to the cell since the cytosol has a pH ≈ 7.2 and will make lysosomal enzymes inactive.

Chapter 2 - Cells

This organelle stains dark and it looks like a big round black circle!



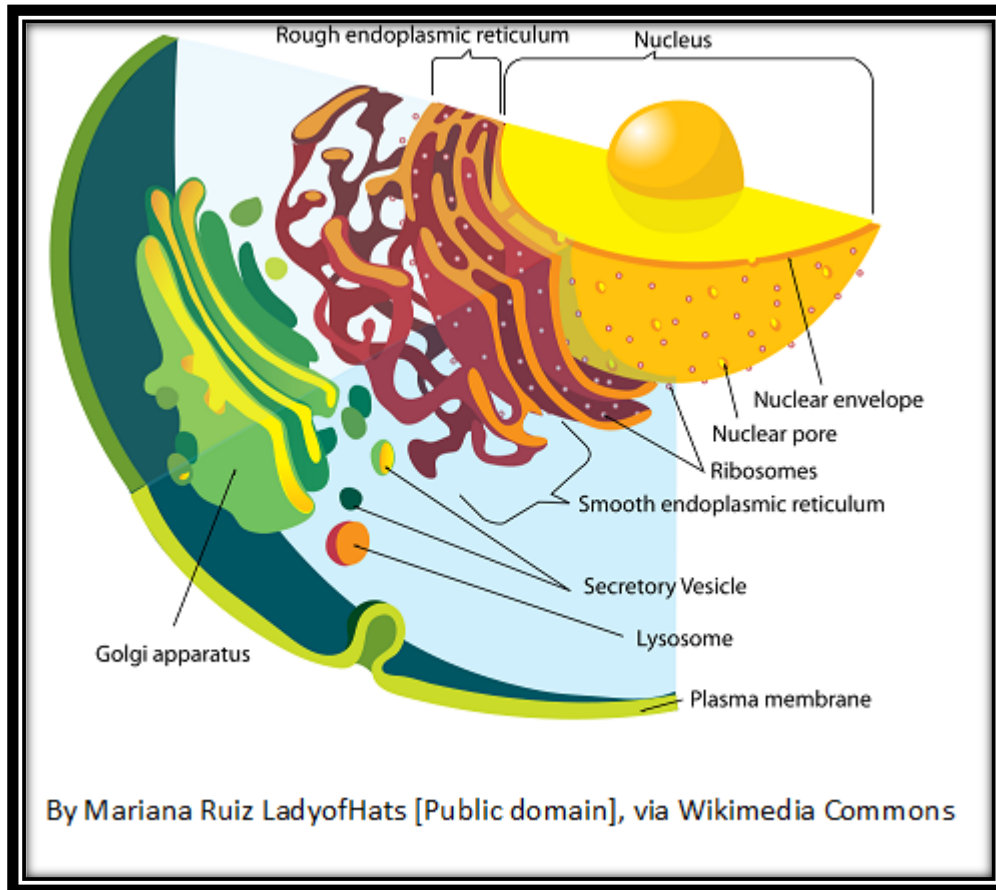
Taken with a transmission electron microscope... these are the suicide bags of the cell

A **phagosome** is formed by the fusion of the cell membrane around a microorganism or senescent cell (a cell that no longer divides).

This phagosome fuses with the lysosome and the enzymes begin digestion. ★ In Tay-Sachs disease, a critical lysosomal enzyme is deficient... lipids cannot be digested, and cells become “engorged” and neuronal function suffers ... the child dies before age 4.

Chapter 2 - Cells

Golgi Apparatus (Complex)



Stacks of membranous “sacs” that is involved with the synthesis of carbohydrates and in the modification of proteins. For example, carbohydrates are added to the protein by Golgi enzymes. In other words, post-translational modification and “packaging” of proteins occur here. Some proteins are glycosylated... we add sugars, while other proteins have sugars removed.

Three main sections:

Cis Golgi: molecules go in

Main Golgi: molecules get processed

Trans Golgi: molecules go outward

We need not go into any more detail, you will be set for the DAT with this.

There are three main destinations for the material being shipped out of the trans-Golgi:

Inside the cell... many are released in vesicles destined to be delivered to the lysosomes.

The Plasma Membrane... many molecules are shipped to be used for repair to the membrane, for cell signaling purposes, etc.

Chapter 2 - Cells

Outside the cell ... such as the release of the hormone insulin.

Lysosomes are formed by budding from the Golgi Complex **(A favorite DAT question)**.

Many of the cells polysaccharides are made by the Golgi and most of the glycosaminoglycans of the extracellular matrix. (In plants, hemicellulose and pectin are made which contribute to the cell wall).

The Golgi is like one big warehouse... where sorting and shipping occurs. It reminds me of Mimeo... the company that ships our DAT Destroyer books to you. Where does the material that went to the Golgi come from? The answer is:

The Endoplasmic Reticulum

This is the largest membranous system in the cell.

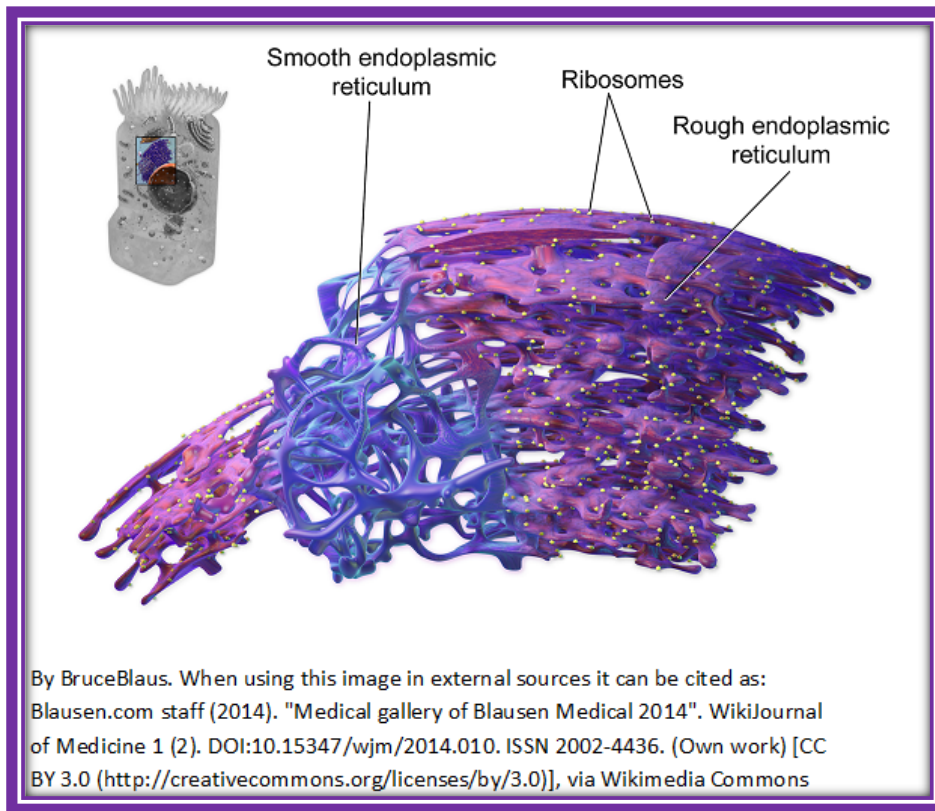
It occupies about 50% of the total membrane volume.

It has two components:

- a) Smooth ER
- b) Rough ER

Chapter 2 - Cells

The Smooth ER... outer surface lacks ribosomes



Involved with lipid biosynthesis such as phospholipids.

Also involved with holding and releasing Ca^{++} in a controlled manner, and released when needed. It is specialized in skeletal muscle and called sarcoplasmic reticulum.

Also involved in steroid biosynthesis and detoxification of drugs and poisons.

Cells that are active in the synthesis of cholesterol, triglycerides, and steroids show an abundance of smooth ER.

In the liver, the Smooth ER contains a large amount of cytochrome 450 and participates in detoxifying certain drugs. The cytochrome 450 catalyzes reactions to decrease drug toxicity. The hepatocyte (liver cell) is involved with drug detoxification, thus has a high % of smooth ER.

Rough Endoplasmic Reticulum

Part of it is continuous with the nuclear envelope! **Know this for the DAT exam.**

In an average liver cell, almost 15 million ribosomes are present. Ribosomes on the Rough ER are “membrane bound” and are involved in protein synthesis.

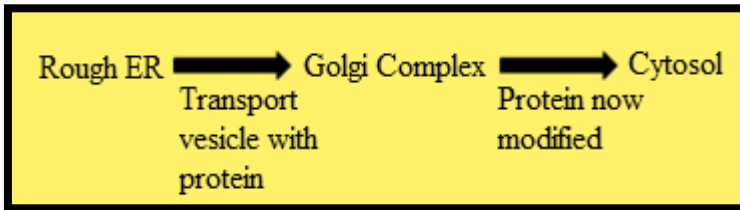
Cells that make enzymes such as pancreas and those of the GI tract have abundant Rough ER.

Chapter 2 - Cells

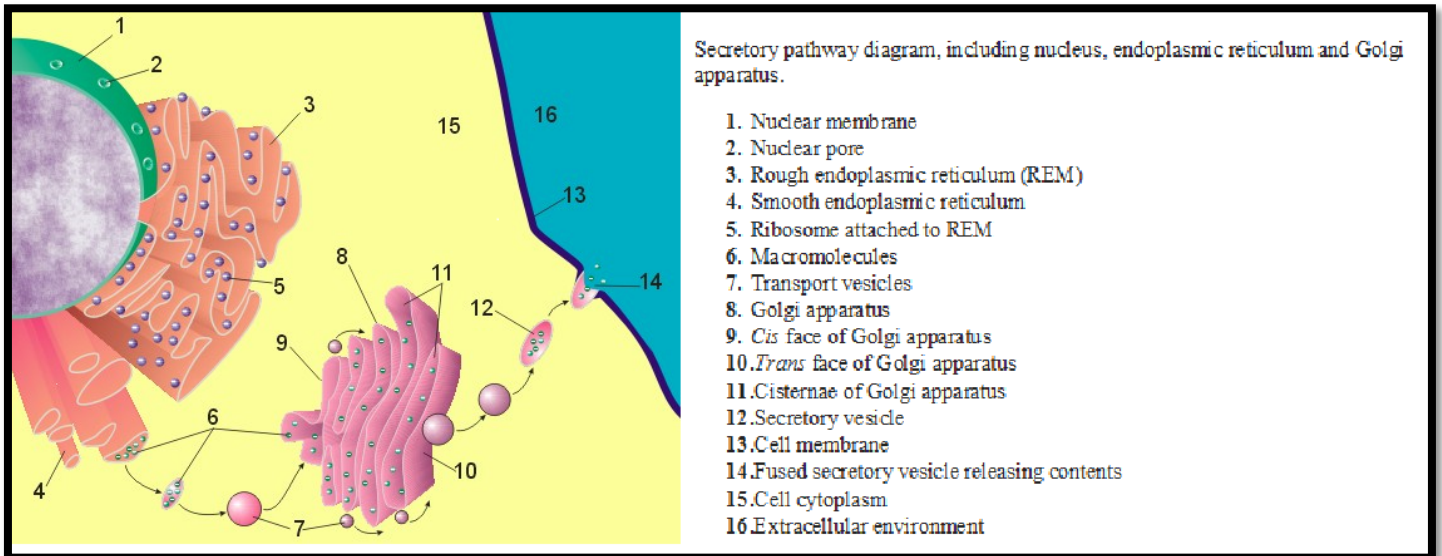
The Rough ER works with the ribosome and continues the **protein assembly**. In most cases, proteins are moved to the Golgi complex for final modification and “finishing”. They are either conveyed in vesicles or moved directly between the ER and Golgi complex before being delivered to their specific locations.

The graphics in the Campbell book on this are excellent. I invite you to have a look, but hopefully you have the idea about this very elaborate transport system.

Bottom Line:

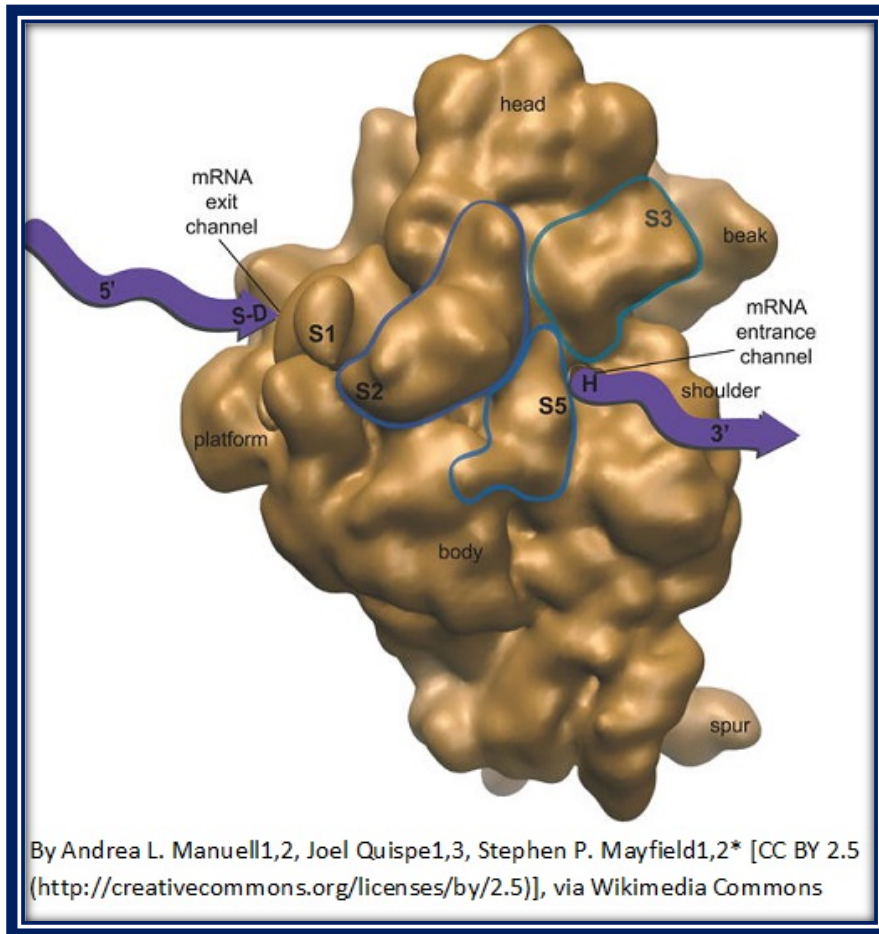


Hopefully you can see the wonderful endomembrane system used in communication between the ER, Golgi, and Lysosomes.



Chapter 2 - Cells

Ribosomes



Found in both prokaryotes and eukaryotes.

“The Protein factories” made of rRNA and over 80 different proteins. This is the site of protein synthesis.
Can be:

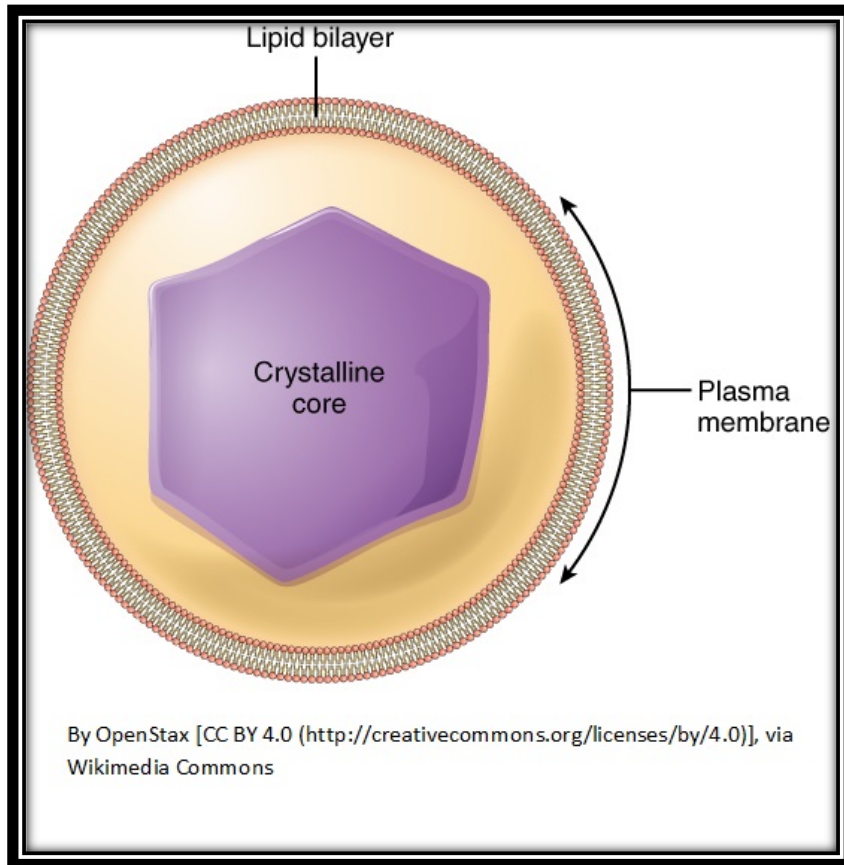
- a) Attached to the Endoplasmic Reticulum
- b) Attached to the Nuclear Envelope
- c) Freely suspended in the cytosol

Cells making an enzyme will have a lot of ribosomes.

They consist of two subunits which are made in the nucleolus of the cell. The subunits are made separately in the nucleolus and exported to the cytoplasm for final assembly. The large and small subunit join together by binding an mRNA strand...

Chapter 2 - Cells

Peroxisome (Microbody)



These spherical organelles are membrane-bound and contain over 40 oxidative enzymes!! One enzyme, in particular I want you to know is **catalase**. Catalase will break down H_2O_2 , hydrogen peroxide, which is harmful to cells. Peroxisomes contain enzymes involved with **lipid metabolism**. The beta oxidation of long chained fatty acids, of 18 carbons or longer, are done by peroxisomal enzymes. These enzymes are different from those of the mitochondria. These fatty acids are made shorter, then subsequently shuttled to the matrix of the mitochondria for oxidation.

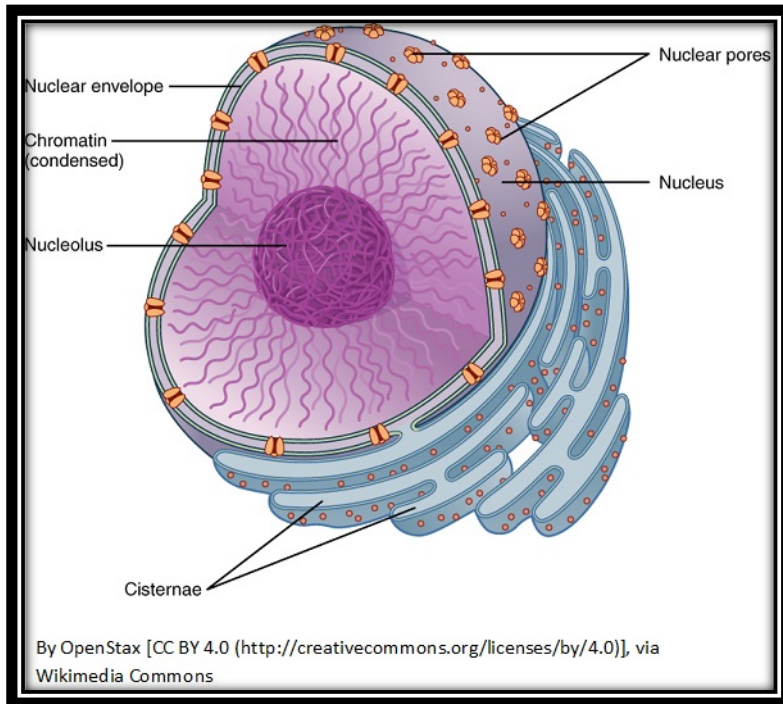
Interestingly, the peroxisome also makes H_2O_2 or hydrogen peroxide. H_2O_2 detoxifies substances such as ethanol and even kills microorganisms. The excess H_2O_2 is broken down by catalase. This is often a very confusing point that I find students don't clearly understand.

They do self-replicate, but unlike the mitochondria lack their own DNA. Hence, they must import the needed proteins for self-replication.

Also, mitochondria generate ATP, peroxisomes do not.

Chapter 2 - Cells

Nucleolus



The **ribosome production factory**... makes ribosomes

Non-membranous organelle

One or more may be found within the nucleus... rarely beyond three.

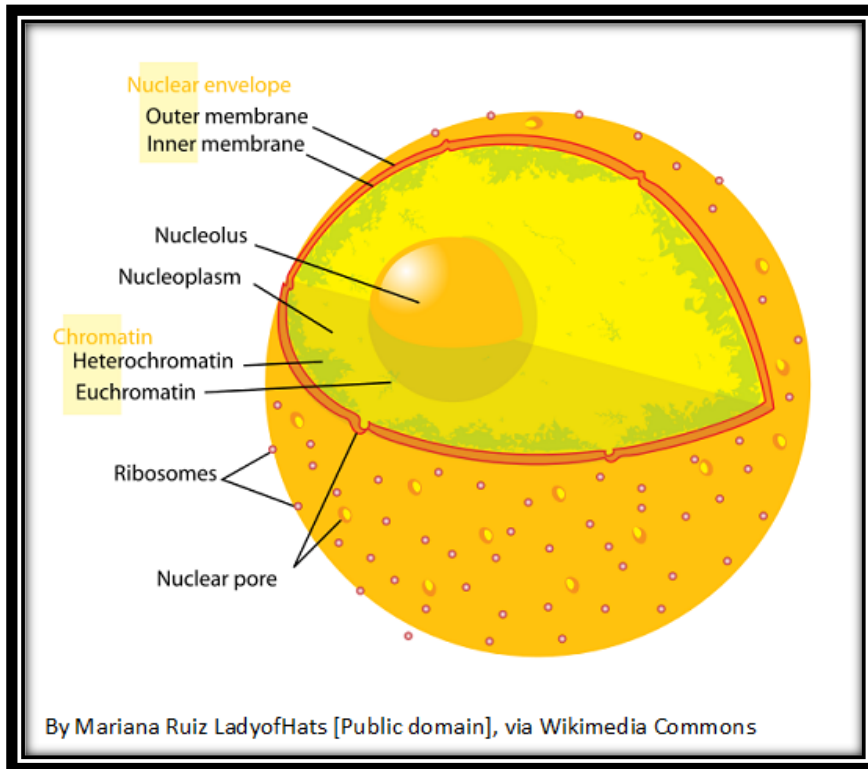
In addition to rRNA synthesis, the assembly of large and small ribosomal subunits occurs here.

Small amounts of DNA are present, but does not stain with Feulgen stain.

Interestingly, in cancer cells, the nucleolus is often hypertrophic meaning increased in size. But, be careful. Large nucleoli are not only encountered with rapidly growing malignant tumors, but are found in cells that are actively synthesizing proteins.

Chapter 2 - Cells

Nucleus



Largest organelle of the cell

In the eukaryotic organism, most of the genes are found here (a small amount is found in the mitochondria and chloroplasts).

It is enclosed by the **nuclear envelope**, which is a double membrane.

Inside the nucleus, DNA is organized into units called chromosomes. The chromosomes are made of proteins and DNA called a chromatin complex.

For humans, we have 46 chromosomes in the nucleus, normally. The germ cells ... sperm and eggs, have 23 chromosomes.

The nucleus, bounded by a pair of lipid membranes has three major components:

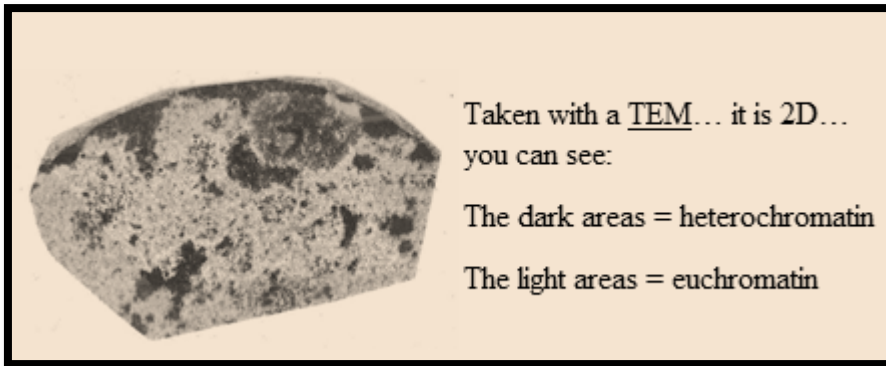
- A) **Nucleolus**: rRNA synthesis
- B) **Chromatin**: genetic material
- C) **Nucleoplasm**: the content of the nucleus, excluding the nucleolus

Chromatin can be either **heterochromatin** or **euchromatin**.

Heterochromatin is **dark-staining** and much is found near the nuclear envelope. It is **condensed** and **not actively transcribed**. The **euchromatin** is the **light area**... less dense... less compact and **has genes that are actively transcribing**. In most cells, more of the DNA is found in euchromatin than heterochromatin. **I have a nice question on this in DAT Destroyer**

Chapter 2 - Cells

Here is what it looks like:



The nuclear envelope contains pores used for importing and exporting materials such as proteins or RNA.

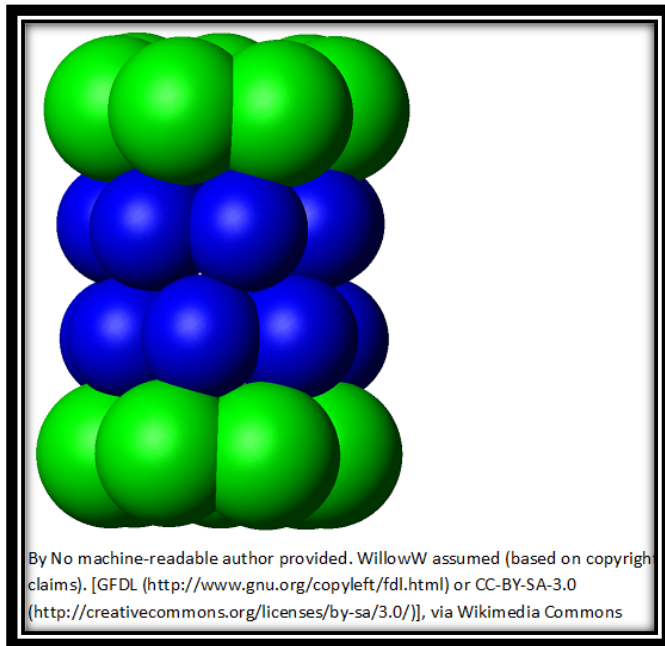
Most cells have a single nucleus, but some cells have multiple nuclei and a few cells have none.

Osteoclasts are cells that break down bone, these are a fine example of a multinucleated cell. (Multinucleated cells can often be found under pathological conditions such as in a malignant (cancerous) tumor). Skeletal muscle cells are also multinucleated. Liver cells are often multinucleated too!

A Red blood cell is an example of a cell that has no nucleus. Platelets (thrombocytes), which are involved with blood clotting also have no nucleus.

Chapter 2 - Cells

Proteasomes



These are protein complexes found in the cytoplasm about the size of a ribosomal subunit (small).

They degrade denatured or unneeded proteins. Think of proteasomes as the quality control protein department.

Lysosomes do the bulk of the job, but these organelles assist with primarily individual proteins.

Recent studies have shown that they remove abnormal or misfolded proteins and use ATP to drive the needed conformational changes in their subunits.

A very cool structure... check this out... note the four stacked rings!!

Inclusion

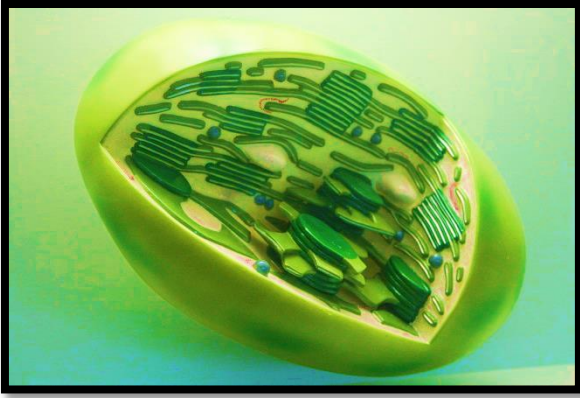
What is an inclusion?

These are the nonliving components of a cell. Inclusions include:

- a) Pigments... melanin pigment in skin and hair
- b) Lipid droplets in fat cells
- c) Glycogen granules in liver and skeletal muscle cells
- d) Vacuoles... membrane bound vesicle... more prominent in plants. They can be used for storage.
- e) Crystals... likely remnants of certain proteins

Chloroplast

Chapter 2 - Cells



A plant organelle... the **site of photosynthesis**.

Contains the green pigment **chlorophyll** which absorbs light energy to convert CO_2 and H_2O into O_2 and sugar!

Like mitochondria, contain their own DNA... and yes, it is circular!! Mitochondria and chloroplasts were once likely prokaryotes that got ingested by larger cells... this was the **Endosymbiont Theory**.

Inside the chloroplast, we find flattened sacs called **thylakoids**. These thylakoids may be stacked like pancakes... each stack is called a **grana**.

The fluid outside the thylakoids is called **stroma** which has the DNA, enzymes, and ribosomes.

Like the mitochondria, they have a **double membrane**.

Thylakoids contain hundreds of different proteins and is still being investigated.

Cyanobacteria give us O_2 !! They represent the only form of oxygenic photosynthetic bacteria known to date. These bacteria contain chlorophyll, and perform photosynthesis similar to plants. Cyanobacteria are mainly found in water, but can be found on corals, rocks, and even land.

Cyanobacteria used to be called blue-green algae, but we try to avoid it. Remember, these cyanobacteria are from Kingdom Monera and represent prokaryotes.

Prokaryotes are unicellular, and lack a membrane-bound nucleus, mitochondria, and other membrane-bound organelles.

The Cytoskeleton

Complex network of:

- a) Microfilaments (actin)
- b) Microtubules
- c) Intermediate filaments

They determine the shape of cells and play an important role in movements of organelles, vesicles, as well as entire cell movement.

Chapter 2 - Cells

As you know, sperm cells can swim and white blood cells crawl across cell surfaces to destroy invaders. These cells are powered and guided by the cytoskeleton.

The cytoskeleton polymers are composed of many subunit proteins, and is always reorganizing itself. Sometimes it loses subunits, other times it gains subunits.

Microtubules are involved with “molecular motors” ... attaching to organelles and vesicles as well as chromosomes to help pull them apart.

Drugs such as **colchicine** disrupts the microtubules and is used to treat gout. Microtubule disruption blocks white blood cell migration which is responsible for inflammation.

For the DAT... make sure you know colchicine is a “Mitotic Poison” ... it messes up the microtubules. Thus, I hope you can see that mitosis would be halted!!

The drug often used for ovarian and breast cancer is Taxol. This drug will bind to the microtubules and prevent them from disassociating. Another clever way to stop mitosis. Recall, a cancer or malignancy represents an uncontrolled mitosis.

★ Cilia and flagella are composed of **microtubules** and motor proteins and are used for movement.

Microtubules are the strongest of the cytoskeletal polymers. Most cells would lose their shape if microtubules are depolymerized!! Microtubules are organized to suit the needs of each cell. A mature neuron, for example, uses microtubules for strength, while a young neuron uses microtubules to help with movement.

Believe it or not, books are written about microtubules. **This will suffice for the DAT and I think you see the importance of microtubules.** If you go to YouTube you will see a cool video. **Molecular motors** are enzymes that will walk along microtubules. These molecular motors include **Dyneins (favorite DAT question-type)** and **kinesins**. These molecules can generate enough force to literally walk across the microtubule!

Bottom Line: Dynein “walking” is responsible for the bending movements of the cilia and flagella.

Size: microtubules > intermediate filaments > microfilaments

Microfilaments

Built from **actin** (a globular protein). Like the motor protein dynein, myosin is another motor protein that loves to walk. However, it is microfilament-based and not microtubule-based like dynein.

Myosin “walks” along the actin filaments. Recall, this is seen in muscle contraction. I hope you remember that the actin and myosin filaments slide past one another.

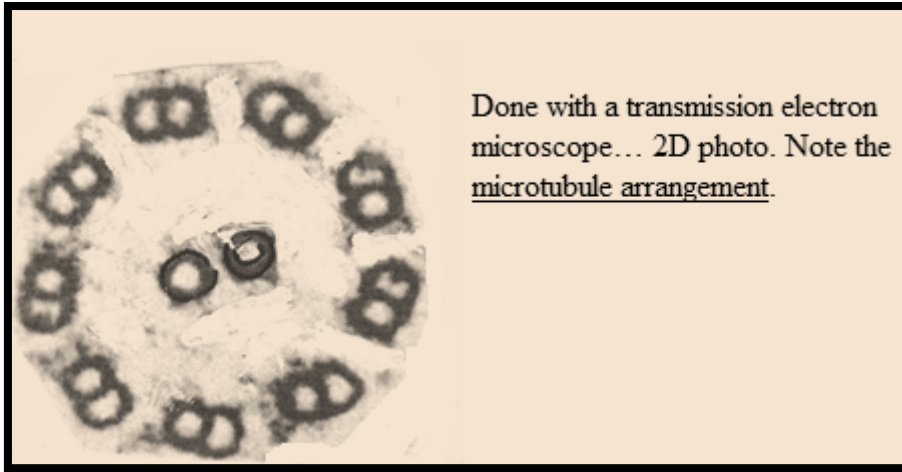
Amoebas move by **pseudopodia** and this movement also involves actin and myosin.

Cytoplasmic streaming is the movement of the cytoplasm in plants or animals, it is also believed to involve actin and myosin.

Actin also plays a critical role in cytokinesis and phagocytosis.

Chapter 2 - Cells

Recall the “9+2” pattern of the flagella and cilia – **a sure bet to appear on the DAT!!**



This entire picture of the 9+2 arrangement along with the proteins constitutes what is called an **axoneme**.

In most eukaryotic cells, actin is the most abundant protein, and participates in more protein-protein interactions than any other protein.

Intermediate Fibers

More “permanent” structures than microtubules or the microfilaments. After cell death, they are often still seen.

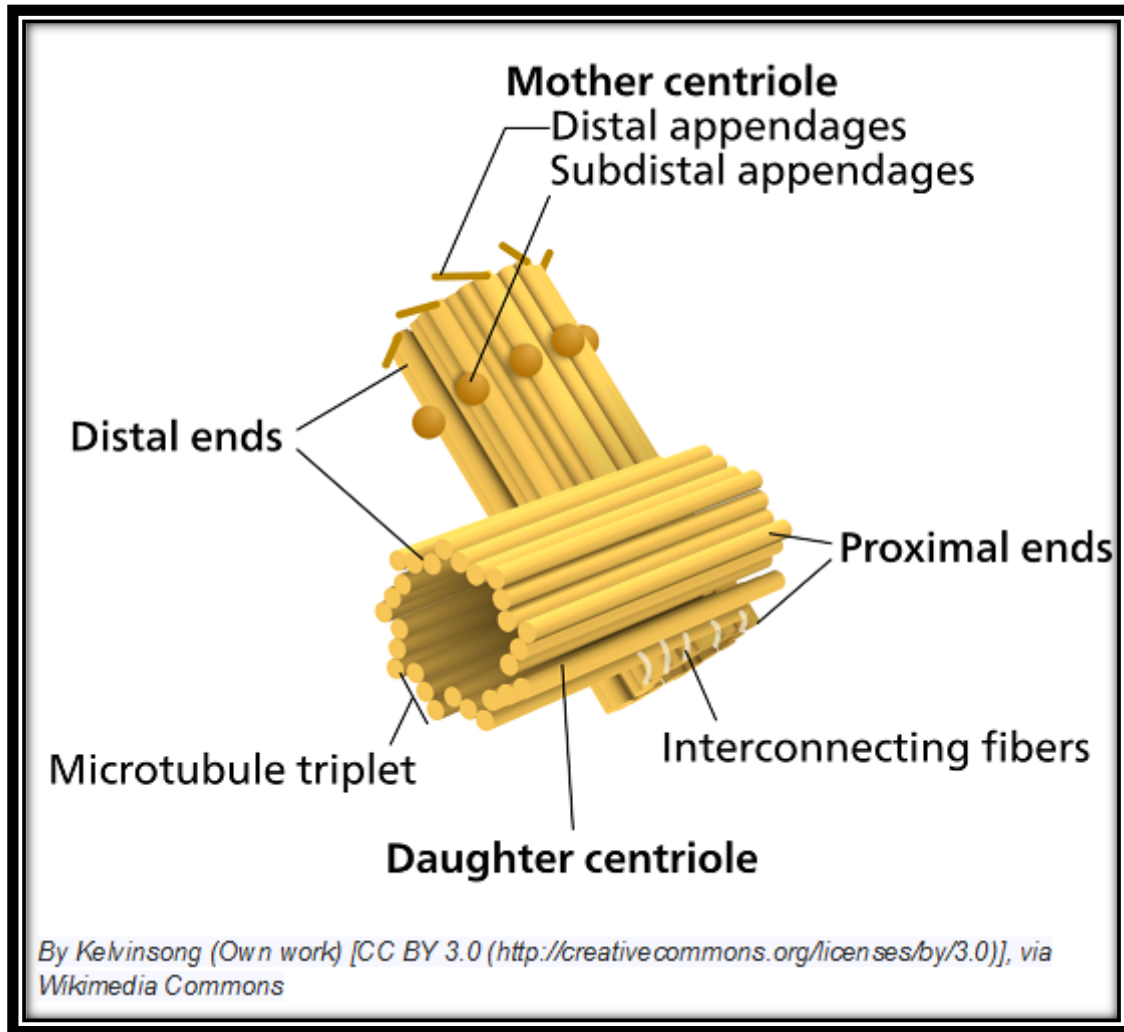
These fibers **anchor** the nucleus in place and provide much structural support for the cell. They also make up the framework of the nuclear envelope.

Keratins represent a predominant type of intermediate fiber. Keratins are actually a diverse family of over 20 proteins that provide protection against abrasion and prevent water loss in epidermal cells. **A “must have” for the DAT... I have written a few Destroyer questions on this stuff that you will be delighted with.**

Chapter 2 - Cells

Centrioles

Found in animal cells, not plants. They are composed of 9 sets of microtubule triplets arranged in a cylinder.



A “9 + 0” pattern!!

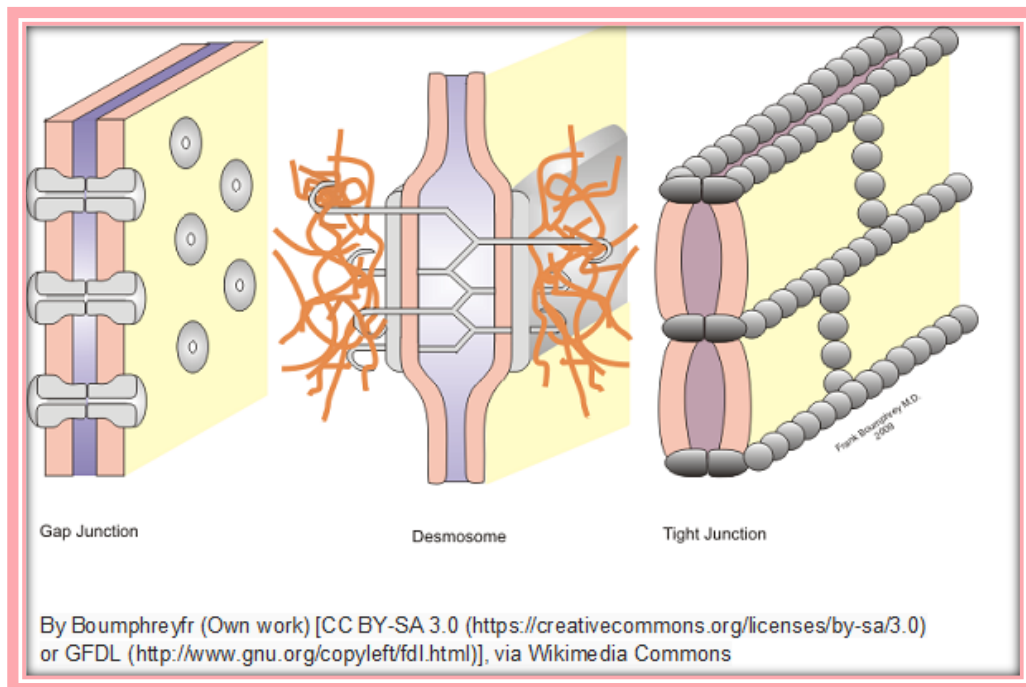
The “centrosome” is the most common **microtubule-organizing center**... MTOC within the cell. A pair of centrioles and associated proteins comprise the centrosome. The centriole pair is perpendicular to each other!!

Before an animal cell divides, centrioles replicate.

Chapter 2 - Cells

Recall, during cell division, centrioles moved to opposite ends of the cell. Microtubules extend from the centrioles to form the spindle. Some of the microtubules attach to the chromosomes by connecting to protein complexes called kinetochores that are present on each chromosome. The kinetochores control the metaphase/anaphase transition.

Intercellular Junctions



Cells often communicate with each other and are not isolated. Let us look at a few intercellular junctions:

Gap Junctions

Allows communication to occur between cells. We see membrane proteins that surround a pore that will allow substances such as small molecules, amino acids, and ions to pass. The proteins of gap junctions are called **connexins**.

Many types of tissue such as muscle and heart contain these junctions.

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Rapid exchange occurs between these junctions. Cyclic AMP which is involved with cell signal transduction can easily move. Gap junctions are responsible for the heart's coordinated beat.

Plants use:

Plasmodesmata which are intercellular channels that connect plant cells. H₂O and small molecules can pass freely between the cells. These microscopic channels traverse the cell wall of plants and some algal cells.

Tight Junctions “Zona Occludens”

Forms tight seals around cells to prevent contents from leaking.

They allow skin cells, for example, to make us watertight, and maintain the integrity of the epithelial barrier.

The intestinal barrier is maintained by tight junctions.

The complex protein structures that regulate the permeability of the intestine is clearly one example of their importance. Chronic diseases such as Celiac disease or inflammatory bowel disease involves a “leaky” intestinal barrier.

Desmosomes

These remind me of “staples” ... they fasten the cells together into strong sheets ... some scientists call them a “spot-weld”. They can attach muscle cells to one another.

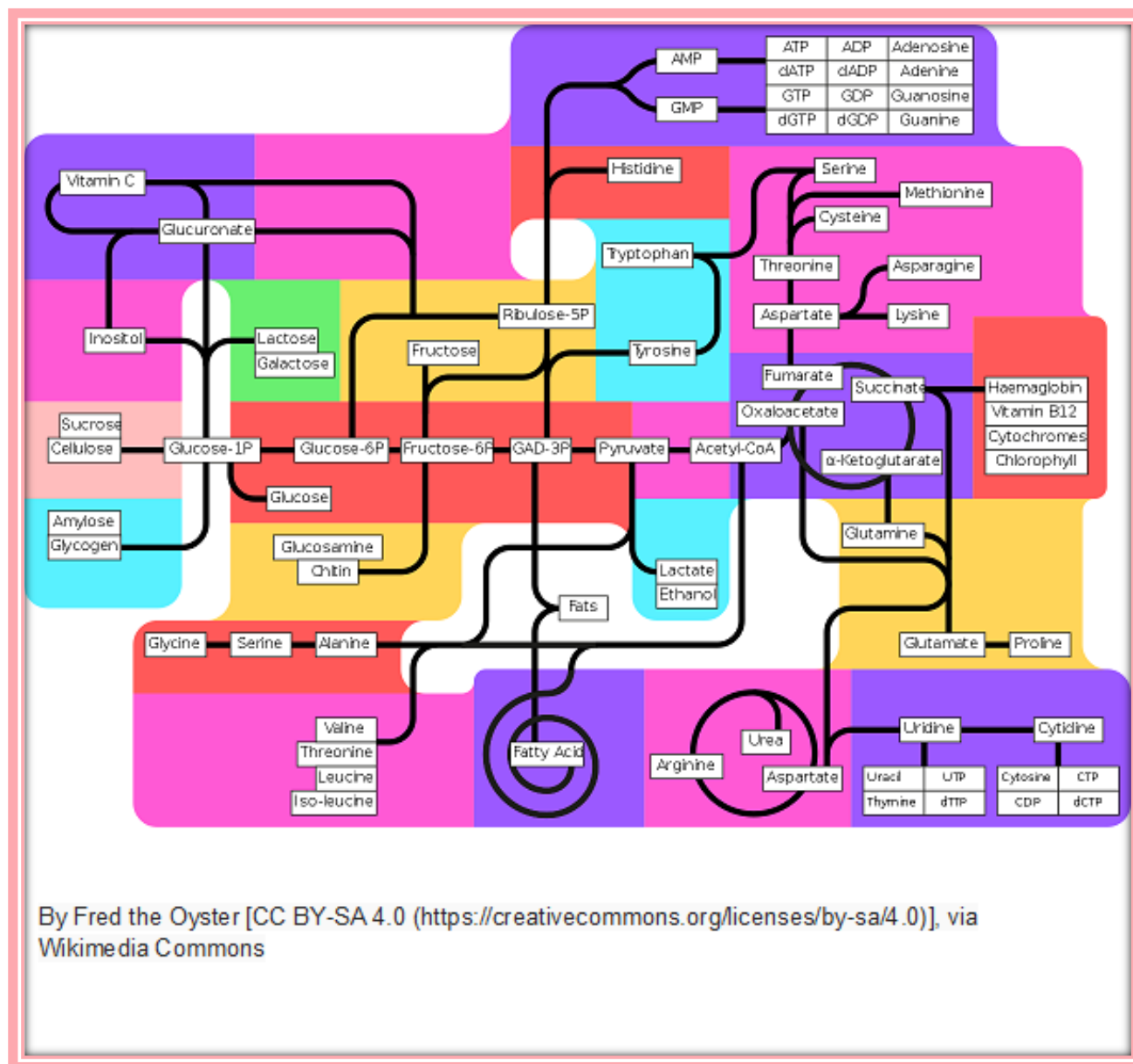
Desmosomes have intermediate filaments which are very strong, they are common in epithelia that need to withstand abrasion such as skin. **(I have some nice problems on this in DAT Destroyer).**

As a future doctor, you might be interested to know that some people produce antibodies against the proteins that make up the desmosome. In a skin disease called **Pemphigus Vulgaris**, we see a disruption of cell adhesion. Many blisters form and loss of extracellular fluid occurs. This can be fatal if not treated. Usually, a steroidal agent can control the pathology.

You are in good shape if you have followed all this. I will take you through a set of notes that are on target for the DAT. I have taught classes that include Organic Chemistry, General Chemistry, Biochemistry, Physical Chemistry, Analytical Chemistry, Biology, Physics, Genetics, Histology, Immunology, Anatomy and Physiology, and Pathology for over 30 years. I have worked making these notes for you all. **Know these notes, and master the Destroyer book along with the explanations and you are likely to be successful in this journey!**

Chapter 3 - Metabolism

Metabolism



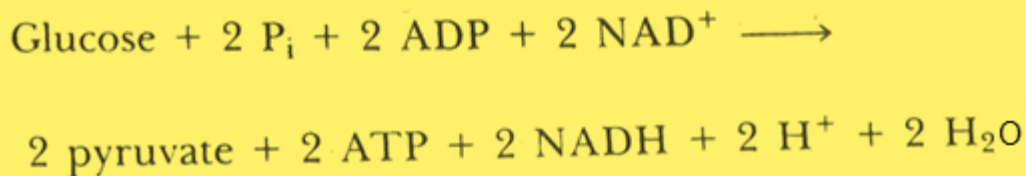
Glycolysis

The DAT will not ask you to memorize all the steps, so relax. I will show you the pathway, and all you need will be the concepts I present.

A total of 9 steps are involved in taking a glucose molecule into **2 molecules of pyruvate**.

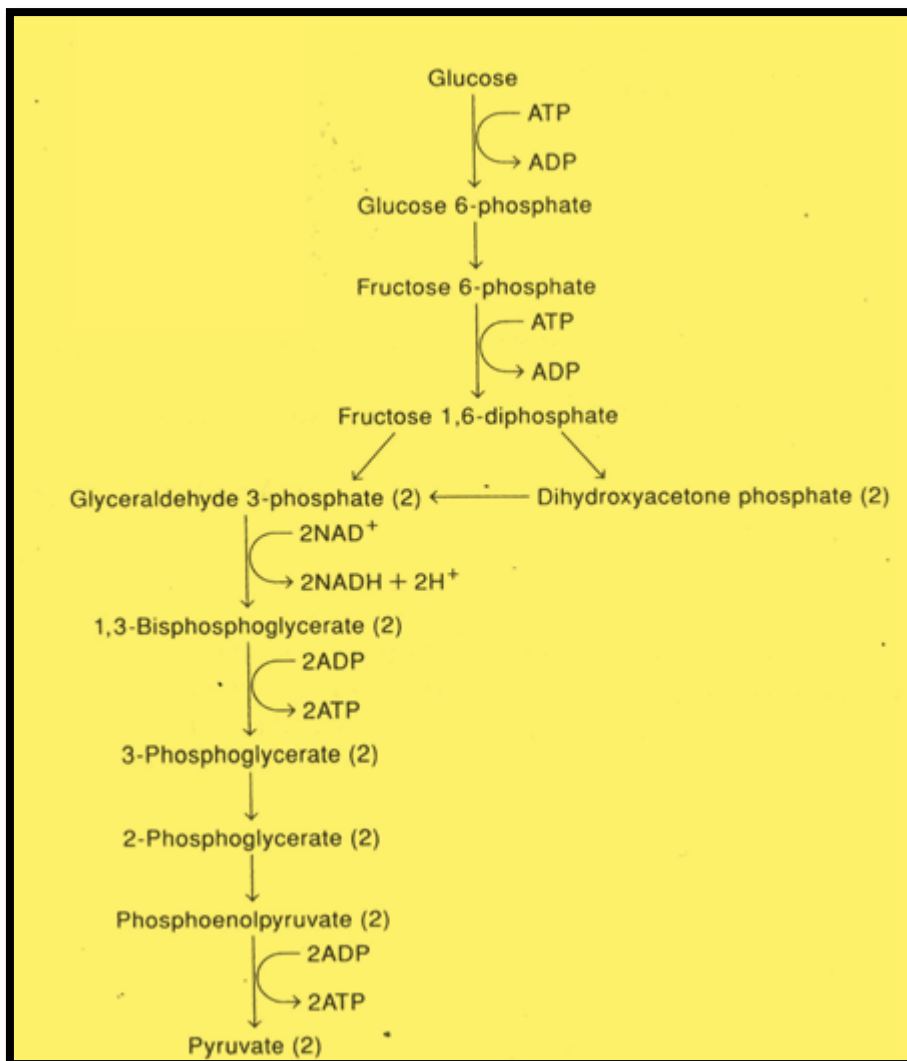
Glycolysis occurs in the **cytosol**. Each step is catalyzed by an enzyme. ATP is used in some steps, generated in others. Overall, we have a **net gain of 2 ATP**.

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This represents **anaerobic respiration**. Anaerobic reactions do not require O_2 . Anaerobic metabolism is the only energy source in mammalian red blood cells.

No need to memorize the pathway, but I will show you the points we need to understand.



shol

In the absence of O_2 , such as in a muscle that is fatigued, the end product in the human body is **lactate**.

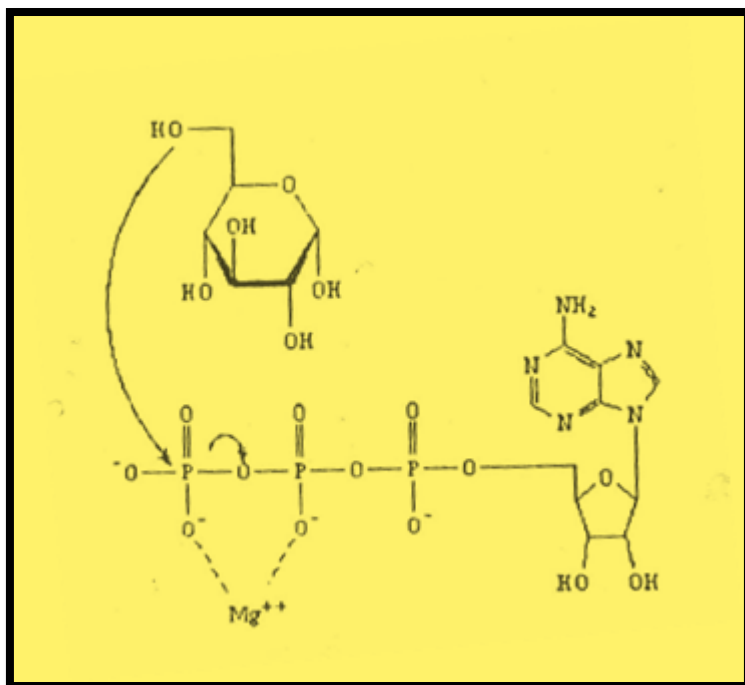
Chapter 3 - Metabolism

Step 1: Is **endergonic**, thus nonspontaneous. The reaction however is driven by coupling it with a reaction that is exergonic, namely ATP hydrolysis.

Once phosphorylated, the molecule cannot leave the cell. It is destined to go forward. We have an irreversible step at the start of the pathway.

Glycolysis has a three-part strategy:

1. It phosphorylates glucose, forming glucose-6-phosphate
2. It converts low energy phosphates to high energy phosphates
3. It used high energy phosphates to convert ADP to ATP



When ATP is utilized in a biological reaction such as those in glycolysis, Mg^{++} is often required to complete the reaction. As shown in the diagram above, Mg^{++} coordinates with two of the negatively charged oxygens on the phosphate chain of ATP, thus shielding their negative charge. As a result, a nucleophile such as the 6'-OH of glucose can more readily attack the phosphonyl group during enzyme-assisted phosphorylation.

The first step uses a **kinase**. **This is an important point.** A kinase will catalyze the transfer of a phosphate group from a high energy molecule such as ATP.

Step 2:

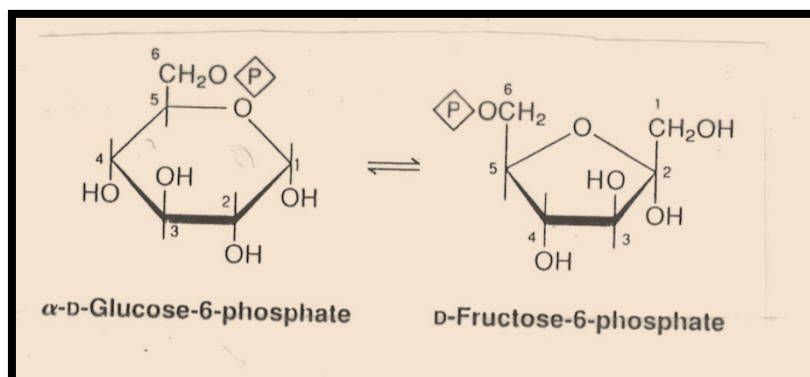
Is another step you need to understand and focus on for the DAT.

We see a glucose being made into a fructose. Recall your organic chemistry... glucose and fructose are isomers.

Glucose: $C_6H_{12}O_6$... an aldohexose

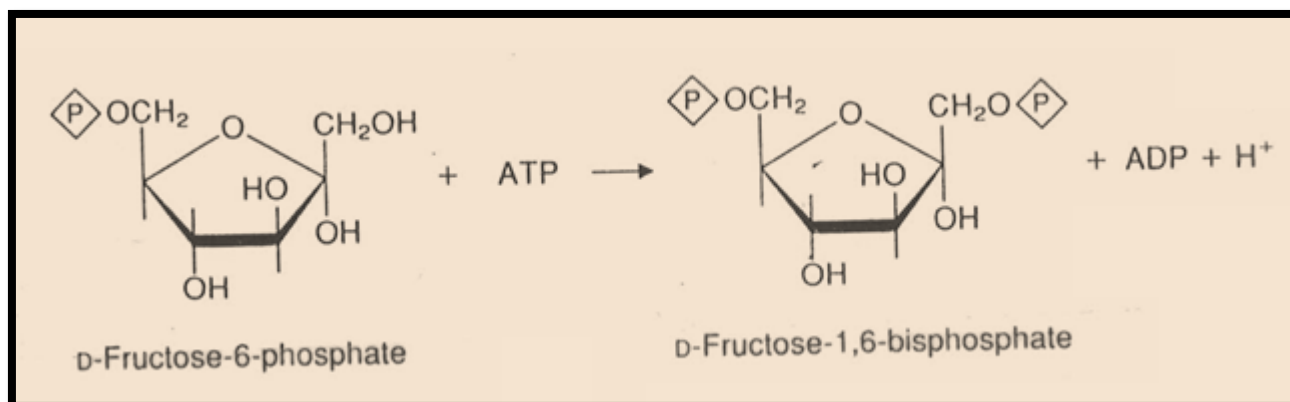
Chapter 3 - Metabolism

Fructose: $C_6H_{12}O_6$... a ketohexose



The enzyme needed is an **isomerase**. Don't worry about the fancy name, but **understand** what it means.

Step 3:



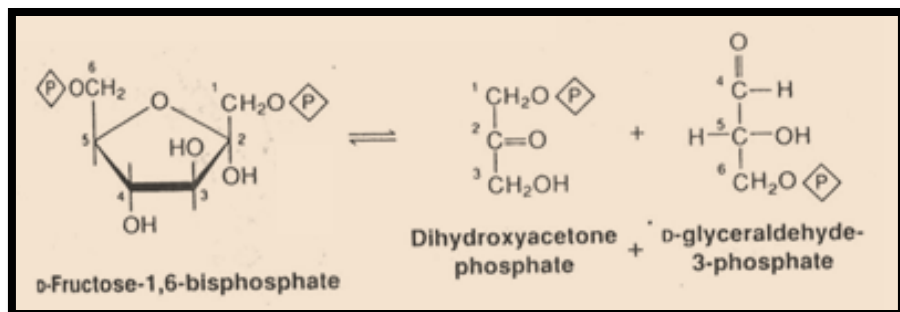
Let's just **understand**, not... I repeat... not memorize step #3. We add on another phosphate group... guess the enzyme type.

I hope you said **kinase**!! This "bad boy" is called phosphofructokinase.

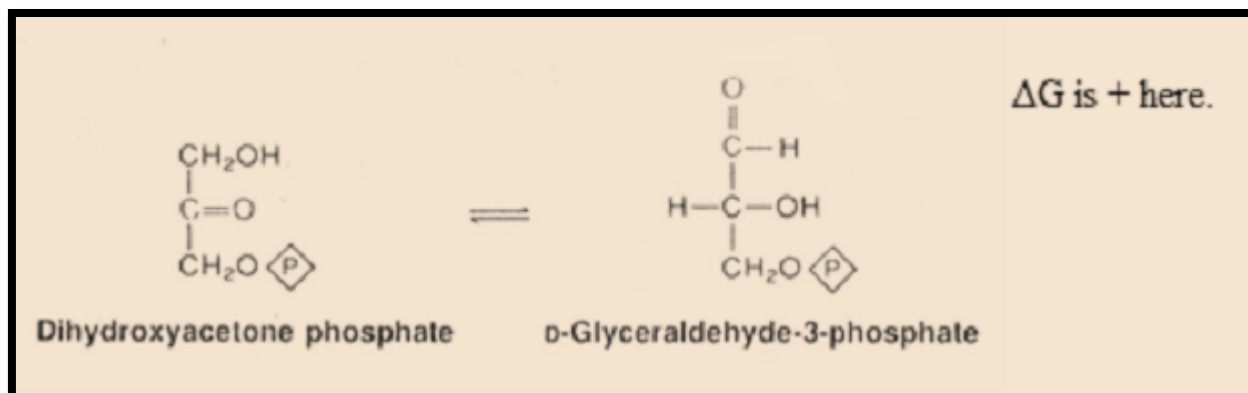
Now... fructose-1,6-bisphosphate breaks apart in what is called a **reverse aldol**. Someday, I seriously need to remember to put this in the Destroyer. We will see all the "copycat" companies following suit.

Let us have a look:

Chapter 3 - Metabolism



This is the “lysis” of glycolysis... we split the sugar molecule. We form a pair of molecules, but only one (glyceraldehyde-3-phosphate) continues on the glycolytic pathway.

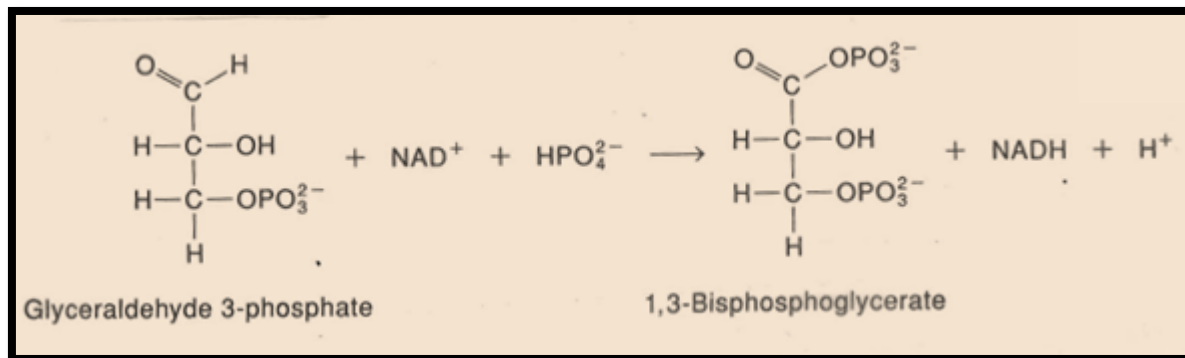


This reaction is also somewhat endergonic under standard conditions, but the intracellular concentration of glyceraldehyde-3-phosphate is low, drawing the reaction toward the right as written.

From this point on... we have two molecules of everything, since dihydroxyacetone phosphate has converted into glyceraldehyde-3-phosphate.

★ The next step is exciting!! We don’t form ATP directly, but we get our first “paycheck”.

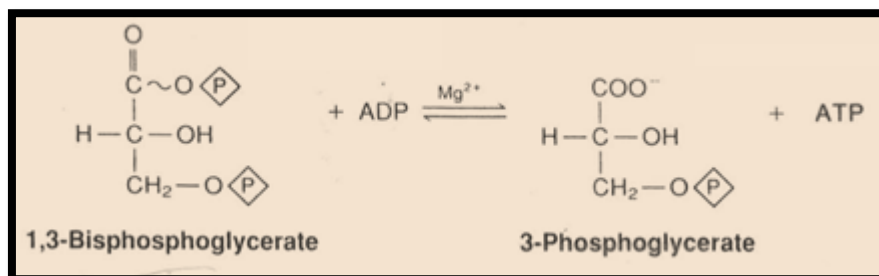
NADH will be cashed in for ATP at the “bank” ... also called the **electron transport chain**.



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The very $-\Delta G$ ensures that this reaction drives forward. The enzyme is a **dehydrogenase**. **A must have name for the DAT exam**. If you see NAD^+ , NADH , FAD , FADH_2 ... you are most likely dealing with a dehydrogenase! Dehydrogenases are a subclass of enzymes called oxidoreductases which are involved with the catalysis of oxidation and reduction-type processes.

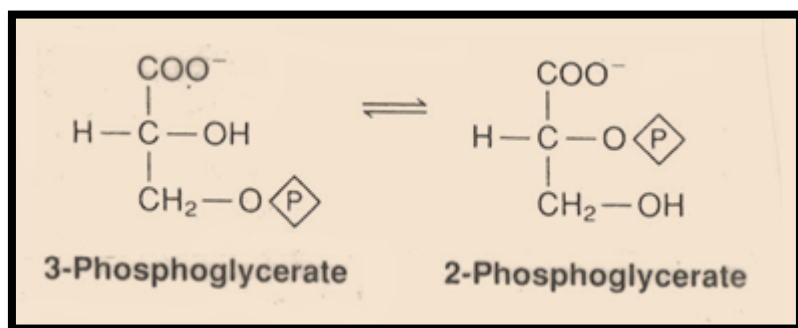
In this next reaction, we make our first ATP!!



★ Since two moles of everything are made, we form 2 ATP!! YAY... our break-even point!!

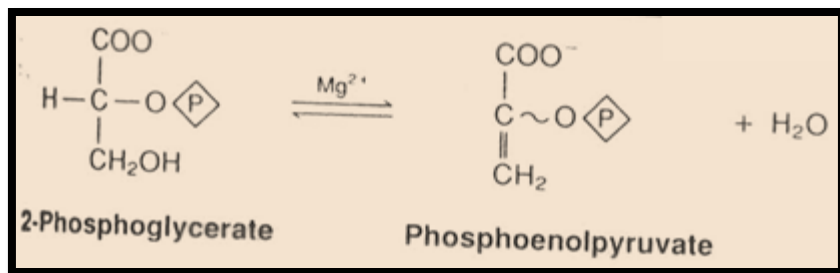
Since an ATP was transferred, a **kinase** is involved. This is called **substrate-level phosphorylation** and **a sure-bet question to land. I have a nice question in the 2018 Destroyer on this**. In substrate level phosphorylation, we see the formation of ATP or GTP by the direct transfer of a phosphoryl group (PO_3) to ADP or GDP from another phosphorylated compound.

We are almost done with our analysis... no memorizing... **just know the concepts**. Relax... we are almost home!!



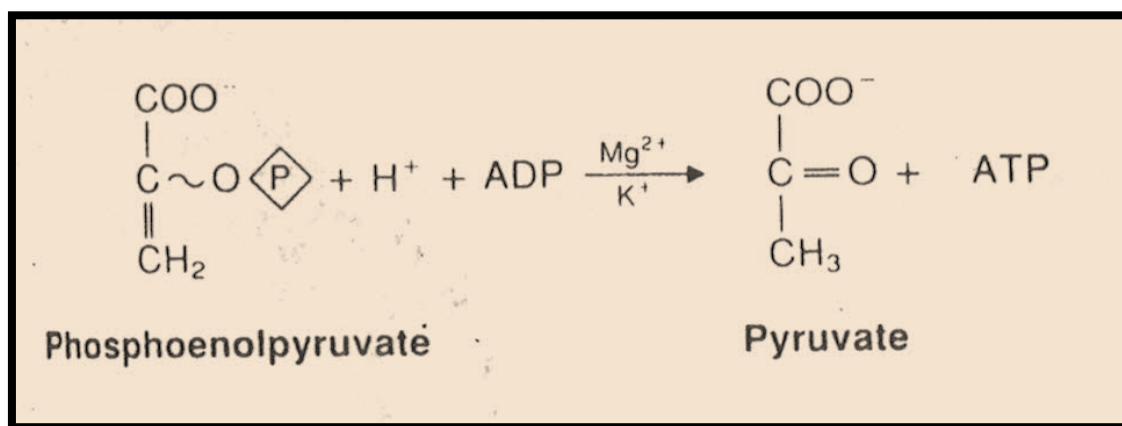
This is an **isomerization**... but we are only “shifting” a group of the same molecule. Instead of an isomerase, we call it a **mutase**. A mutase belongs to the isomerase class of enzymes, if you are curious. Nothing more here... let's move on...

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Here we form a very high-energy molecule called **phosphoenolpyruvate**. I call it PEP, for short. Since water is lost, this is a dehydration reaction.

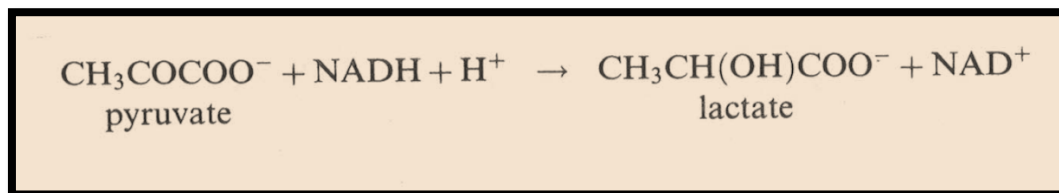
Finally, this high-energy phosphoenol transfers its phosphate group to ADP (think substrate-level



phosphorylation) ... as shown:

Catalyzed by a kinase!!

If O_2 is lacking, the reaction does not stop here, but proceeds to make lactate and NAD^+ . The NAD^+ is recycled for glycolysis.

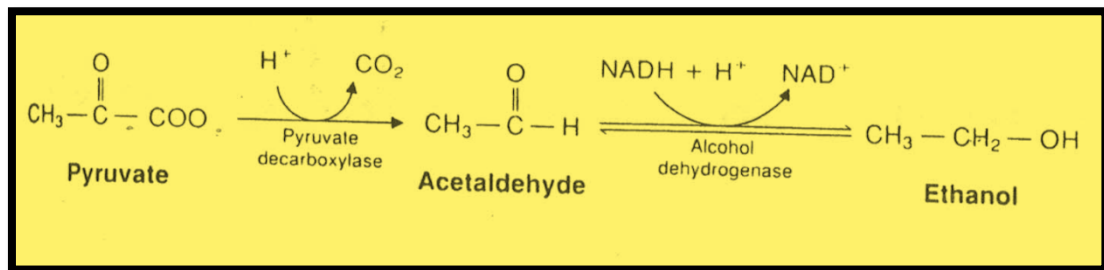


Pyruvate is reduced; NADH is oxidized. You may one day thank me for this. 😊

For anaerobic microorganisms, pyruvate has other fates. The following reaction usually occurs:

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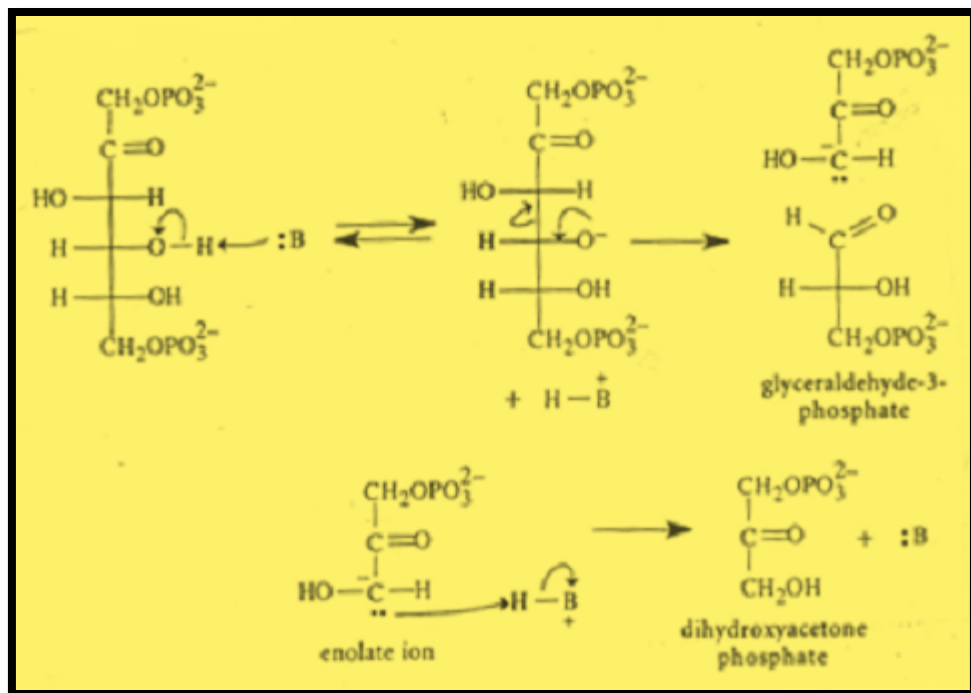
Fermentation



Note the CO_2 made in the step after pyruvate. This CO_2 is why beer and sparkling wine has bubbles. (After doing these bio notes for you all, I sure can use a drink... or two).

For those brave souls wondering just how the fructose-1,6-diphosphate did a reverse aldol... here it is:

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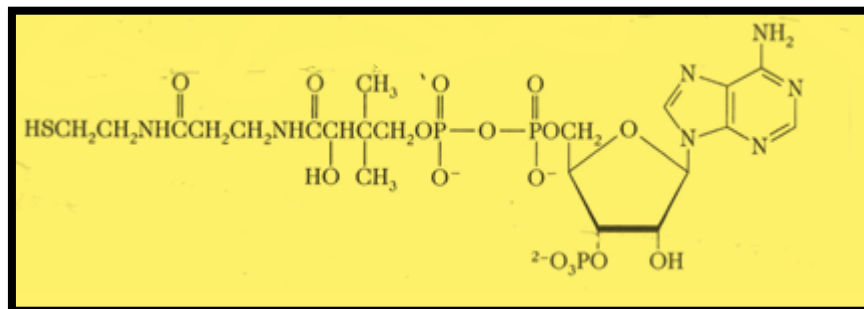
Now that you survived glycolysis and fermentation, we will keep moving.

The Krebs Cycle or TCA Cycle

The Krebs cycle is also called the tricarboxylic acid cycle or TCA cycle.

It occurs in the **matrix** of the mitochondria and represents **aerobic respiration**.

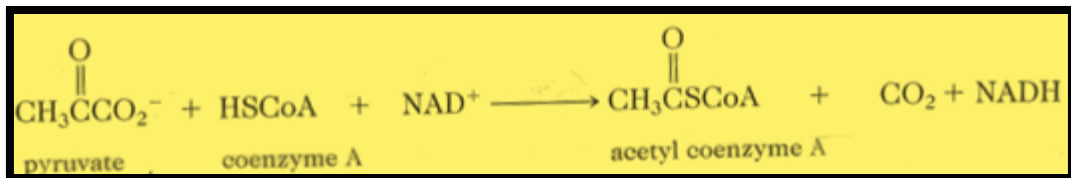
If O_2 is present, let us look at the fate of pyruvate. Pyruvate combines with a molecule called **Coenzyme A**.



Now you see why we just write CoA for this monster!

Now... in the **matrix**, the following occurs:

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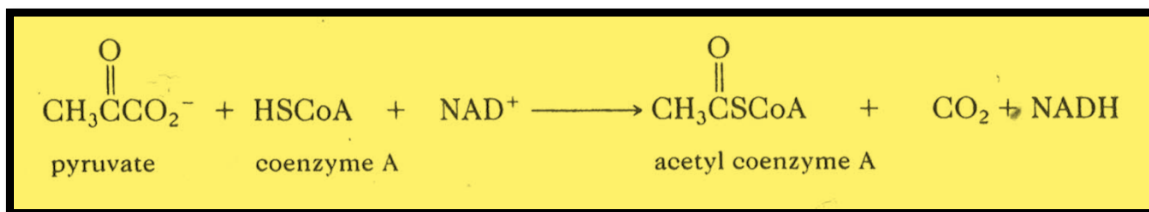


This is an **oxidative decarboxylation** step. I hope you see that CO_2 is lost by pyruvate and most of all... we form the “star” of the show...

Acetyl Coenzyme A. Since NAD^+ and NADH appear here, the enzyme is **dehydrogenase!**

Bottom Line: I will just show you... I repeat... I will show the cycle. The essential thing that you need to understand is that the TCA cycle dismantles acetyl groups converting them into CO_2 and H^- and H^+ into the electron transport chain to produce ATP.

This reaction:



Needs three B vitamins:

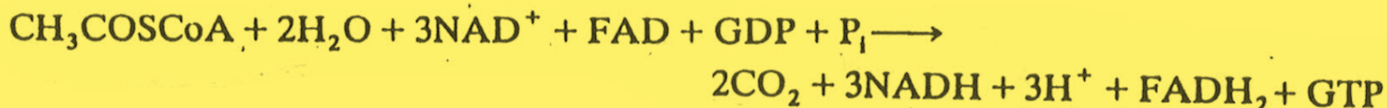
- 1) B_1 ... thiamine
- 2) B_2 ... riboflavin
- 3) B_3 ... Niacin

★ Acetyl CoA contains what functional group?

Thioester!!

The TCA and the enzymes associated with this pathway are contained in the **matrix of the mitochondria**. The only exception to this is **succinic dehydrogenase**, which is part of the **inner mitochondrial membrane**, the **site of the Electron Transport Chain!**

The overall reaction of the citric acid cycle is:



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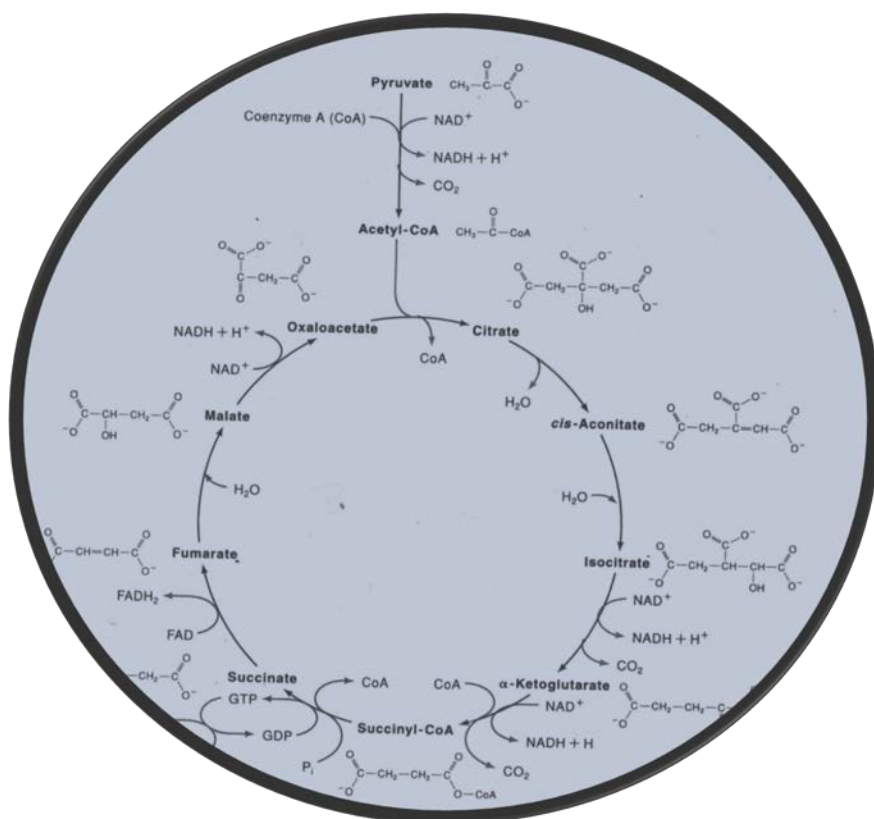
As you will see:

- 1) Acetyl Co A goes into the cycle and reacts with oxaloacetate to give citrate
- 2) 2 turns occur
- 3) Each turn gives 3 NADH, 1 FADH₂, 1 GTP (A GTP will be worth 1 ATP)

I am showing you this. No need to panic or memorize.

However, notice how certain steps yield NADH and FADH₂, and a GTP (substrate-level phosphorylation).

Remember: Acetyl Co A is what enters!!

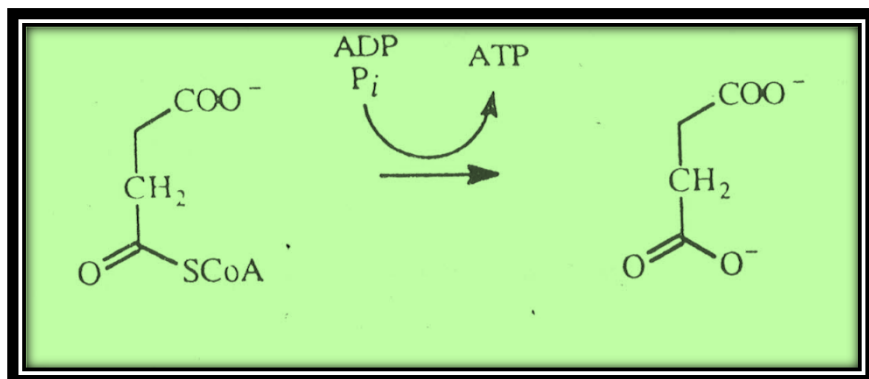


★ The TCA cycle provides numerous intermediates for the biosynthesis of molecules like porphyrins, and even pyrimidine nucleotides!

This cycle is a “metabolic furnace” that will oxidize molecules that come from pyruvate.

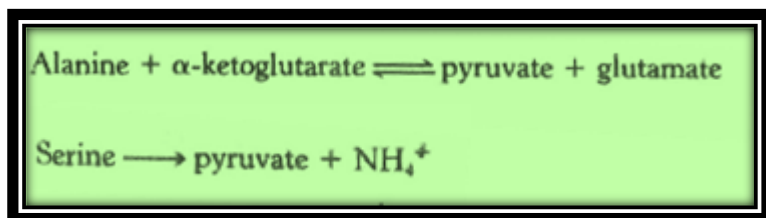
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In the citric acid cycle, ATP is synthesized by substrate level phosphorylation when succinyl CoA synthase converts succinyl CoA to succinate. Explain where the energy comes from to make the ATP molecule.



The energy comes from the hydrolysis of the thioester bond, which yields a very exergonic reaction. Acetyl CoA is not only formed from pyruvate. Lipids can be oxidized into Acetyl CoA units during beta oxidation, and even some amino acids can be made into Acetyl CoA.

No need to memorize, I am only showing you the concept...



Chapter 3 - Metabolism

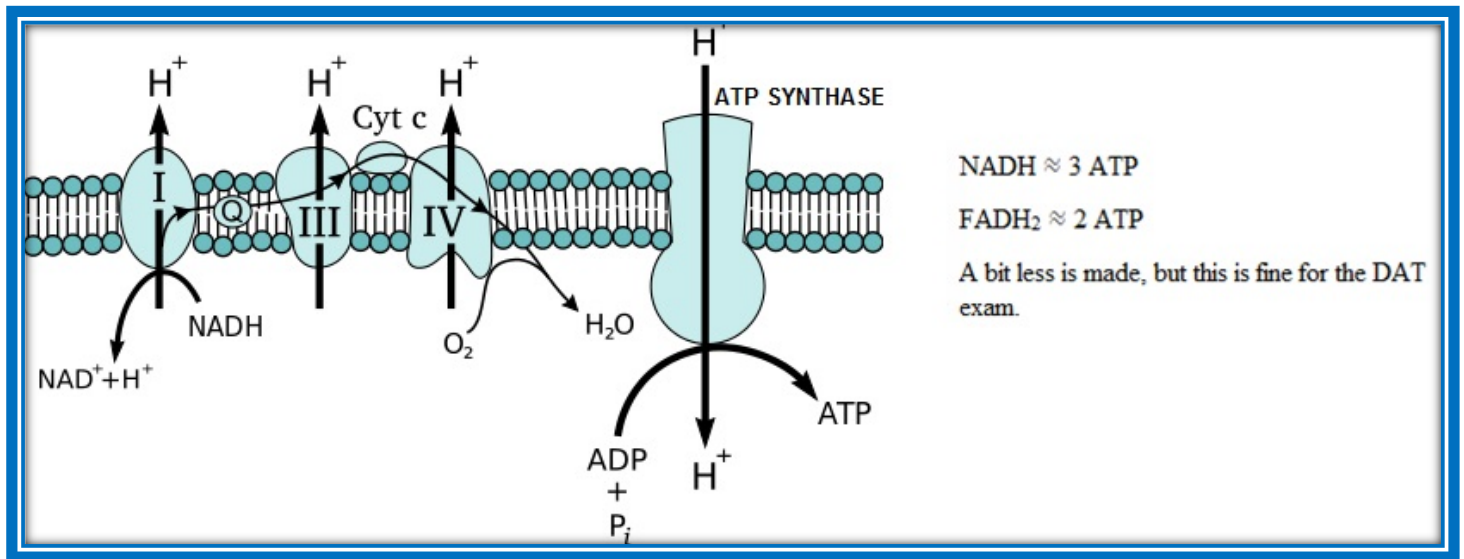
The Electron Transport Chain

The details of this chain are not needed for the DAT, thus I will present to you all the essentials.

About **90%** of the ATP is generated by this system.

The reaction takes place in the **inner mitochondrial membrane**.

The complete series of oxidation-reduction reactions is shown below:

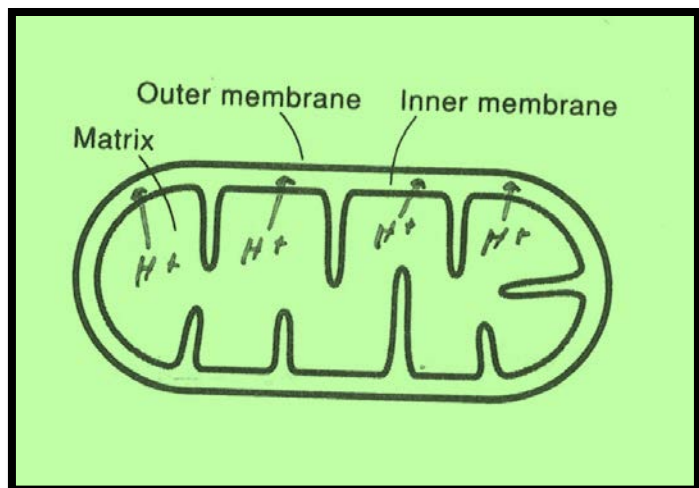


Complex I accepts electrons from NADH, which has been generated earlier. FADH₂ brings electrons to complex II.

As the electrons are moved down the chain, this induces conformational changes in the inner membrane that allows for the H⁺, since it now has been removed off NADH, along with its electron pair, to be **pumped** into the **intermembrane space** from the matrix.

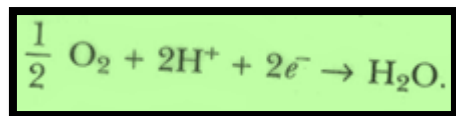
As electrons are moved down the chain (oxidative phosphorylation), we see this movement from the matrix. **This increases the pH on the inside and decreases it on the outside:**

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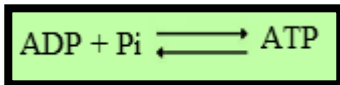


The H^+ flow into what I call the “ATP-machine”. The machine is called **ATP synthase** or ATPase for short. Two things are going on:

- 1) Electrons add to O_2 to form H_2O :



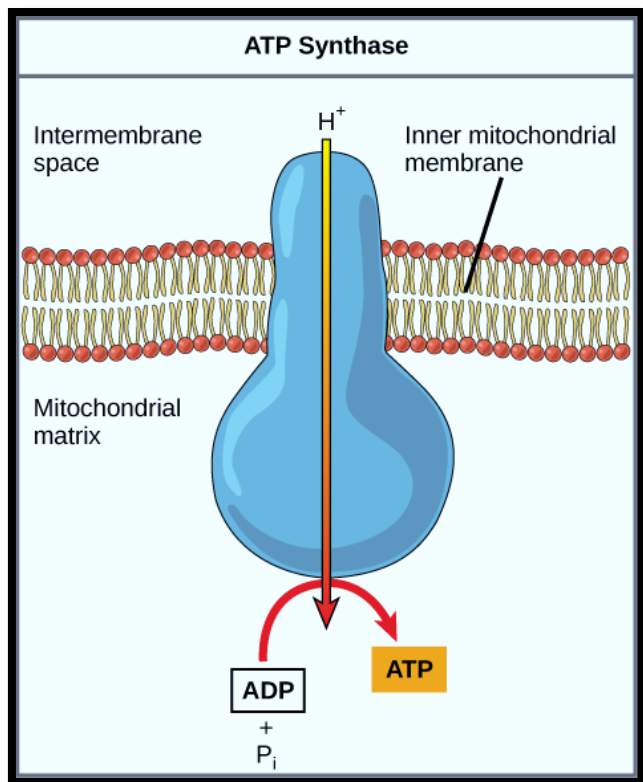
- 2) With considerable simplification for ATP to be made, the following reaction must occur:



H^+ are needed for this reaction to occur.

This is what will occur in the ATPase. You do not need the details for this, but a good general understanding. I hope you can see that the arrival of H^+ within the ATPase causing conformational changes. This will ultimately allow ATP to be made:

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I hope this gives you a solid understanding. This is complicated business, and details will be provided in biochemistry.

Oxidative phosphorylation is the final stage of cellular respiration, occurring in the **inner portion of the mitochondria**. All the enzymatic steps in the oxidative degradation of fats, carbohydrates, amino acids in aerobic cells converge at this final stage of cellular respiration.

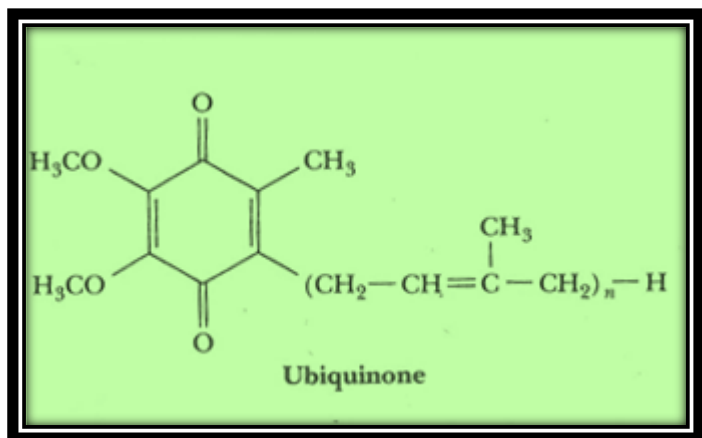
ATP is generated as electrons flow to O_2 . NADH and $FADH_2$, you see, provides the electron donation.

To summarize:

During the process of electron transport, protons are pumped out of the matrix into the cytosol. Since the inner mitochondrial membrane is impermeable to protons, the pumping of protons results in a **proton gradient** across the membrane. This proton gradient is the **basis of the chemiosmotic hypothesis** and is responsible for oxidative phosphorylation by the electron transport chain. The chemiosmotic hypothesis as suggested by Peter Mitchell states that ion gradients represent a high energy state which can be used to drive processes that are by themselves endergonic. The gradient of protons represents both a separation of charge across the inner mitochondrial membrane, which results in a potential (+ to -; outside to inside) and a free energy due to the concentration gradient. Together these constitute a proton-motive force that drives the synthesis of ATP by the ATPase. Thus, electron transport leads to a proton gradient which flows back into the mitochondrion through the ATPase and at the same time the energy is available in this gradient is used to drive the synthesis of ATP. Therefore, electron transport is coupled to oxidative phosphorylation through this gradient.

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For those that are wondering about one of the components here called **CoQ or Ubiquinone**.

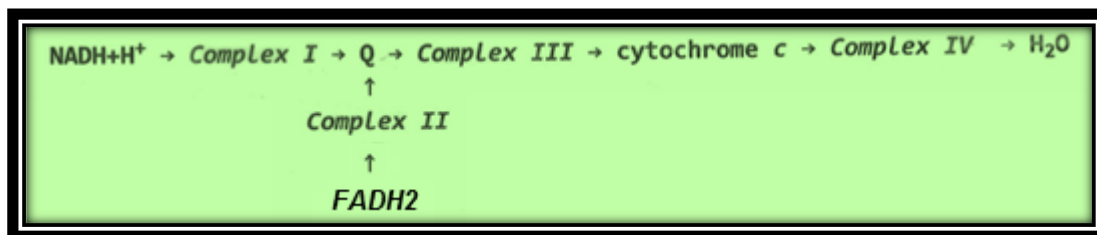


Besides knowing that it participates in the Electron Transport Chain, **I think you are safe for the DAT.**

It is a lipid soluble electron carrier.

It receives electrons from Complex II and Complex I and passes it to Complex III as you see in my previous diagram.

Electrons move as follows:



Gluconeogenesis

This is the synthesis of glucose from non-carbohydrate precursors such as lactate, amino acids, or glycerol.

One of the main mechanisms that allow humans and many animals to keep their glucose levels up to the levels needed to survive.

Occurs in: plants, animals, fungi, bacteria, and many microorganisms.

This is the process that occurs during:

- 1) Starvation
- 2) Low carb diets
- 3) Fasting
- 4) Intense exercise

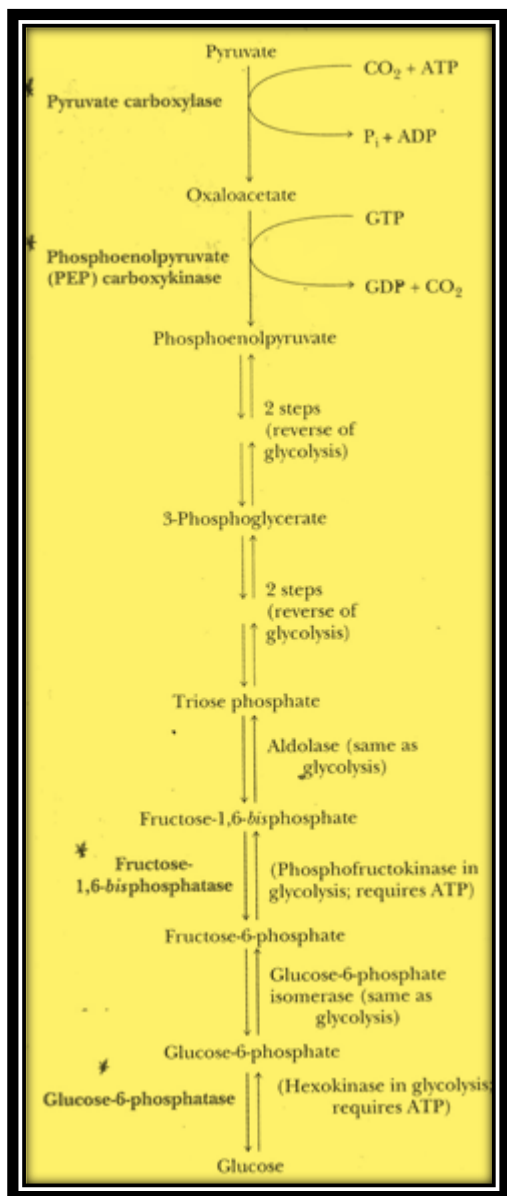
It occurs mainly in the liver and a small amount in the cortex of the kidney.

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It begins in the **mitochondria** and then goes to the **cytosol**. Many of the reactions are the reverse of glycolysis but not all.

I will present the pathway, but no need to memorize it. Just understand the purpose of this pathway and how it resembles the glycolytic pathway.

I have starred (*) those enzymes unique to this pathway. Again, no need to memorize!



In glycolysis, 3 steps are very **exergonic**. Too much energy would be needed in gluconeogenesis to simply reverse course. It is like skiing down a mountain. Going downhill is fun, but try walking back up!! In order to overcome this problem, three new enzymes were “created” by nature.

I will not go into the details, but as you can see, thermodynamics dictates the reason we needed a slightly different route.

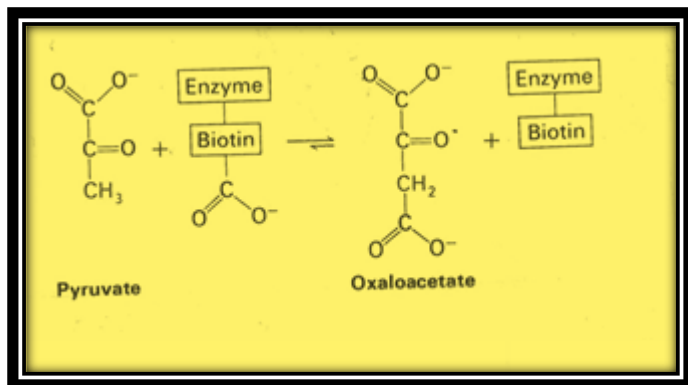
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Can fat be used in gluconeogenesis?

A majority of the carbons in fat is unavailable for incorporation into glucose because they are converted into Acetyl CoA units. However, the glycerol backbone can be used as a C source for gluconeogenesis!

One interesting thing I would like to point out to you:

Look at how pyruvate was converted into oxaloacetate:



Biotin is involved with adding on a CO₂ group. **A commonly asked exam question.**

Remember: Biotin = CO₂ carrier

Gluconeogenesis is responsible for taking lactate produced during anaerobic metabolism and converting it into glucose in the liver by what is called the **Cori Cycle**.

Bottom Line: When ATP is needed, glycolysis is active; when there is little need for ATP, gluconeogenesis is more active.

One enzyme is located in the mitochondria, but all the rest of the gluconeogenesis enzymes are cytoplasmic.

Let's talk a bit about **starvation**.

We can starve for about three months before we die, but carbohydrates are exhausted within one day.

The brain cannot tolerate low glucose levels for even a short time. The brain and red blood cells are absolutely dependent on this fuel.

Like an overnight fast, the first day of starvation sees a decreased secretion of insulin and an increased secretion of glucagon.

Triglycerides in adipose tissue and gluconeogenesis by the liver are the dominant processes. Muscle now shifts from glucose to **fatty acids** for fuel!!

The Beta Oxidation of fatty acids halts the formation of Acetyl CoA from pyruvate.

This is an important point for you all to understand. About three days of starvation will result in an important change... large amounts of compounds called **ketone bodies** are formed by the liver.

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Ketone bodies are made from Acetyl CoA since the TCA cycle is unable to oxidize all the acetyl units formed from fatty acid breakdown. No need to memorize, but the ketone bodies include:

- A) Acetone
- B) Acetoacetate
- C) D-3-hydroxybutyrate

The liver produces large quantities of these ketone bodies which are released into the blood.

The brain utilizes the Acetoacetate in place of glucose!! The heart also uses ketone bodies as fuel.

After several weeks, the brain uses ketone bodies as a major fuel. Clearly you see the need for glucose has diminished. The duration of starvation is mainly determined by the amount of fat you have stored!!

After fat depletion, our only source is **protein**. Protein depletion is not as forgiving as fat, and death results from the loss of organ function.

In **diabetes mellitus** glucose is not oxidized, thus fatty acids must be oxidized to compensate for the unavailable energy. Ketone bodies are formed, and a condition called ketosis is seen. Just like in starvation, we have ketosis.

Thus, all I want you to understand is that instead of just getting energy from glucose, we get some of the body's energy from ketone bodies.

Prolonged ketone body formation results in **acidosis**... if blood pH is below 7.35.

Thus, to conclude... most body cells use both glucose and ketone bodies for fuel, but during ketosis, we see free fatty acids and glucose made from gluconeogenesis fuel the remainder.

The Pentose Phosphate Pathway

This pathway is primarily anabolic and has two main purposes:

- 1) Provides NADPH... reductive biosynthesis of lipids
- 2) Provides ribose-5-phosphate... nucleotide and nucleic acid biosynthesis

All reactions occur in the **cytosol**. This pathway is also called the Pentose Shunt or hexose monophosphate pathway.

This pathway is quite active in adipose tissue such as the mammary gland. Since NADPH is used to make fatty acids and steroids. Tissues such as adrenals, liver, and adipose tissue also have an abundance of enzymes of this pathway.

Hopefully you can see, glucose-6-phosphate has other routes other than glycolysis.

I think for the DAT exam this will suffice.

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Glyoxylate Cycle

Plants such as seedlings which cannot carry out efficient photosynthesis, some bacteria and algae can use acetate as a carbon source for all the carbon compounds they produce. It is a Kreb-Cycle (TCA Cycle) modification. The enzymes of this cycle are found in organelles called **glyoxysomes**.

★ This cycle allows certain seeds to grow in the dark or underground (this should have been a DAT Destroyer question!!) where photosynthesis is impossible.

It is possible to target specific enzymes of the glyoxylate cycle in pathogenic fungi and pathogenic bacteria and make drugs that inhibit these enzymes. I have read work done on the bacteria that cause tuberculosis, and the drug design involves glyoxylate cycle enzyme inhibitors.

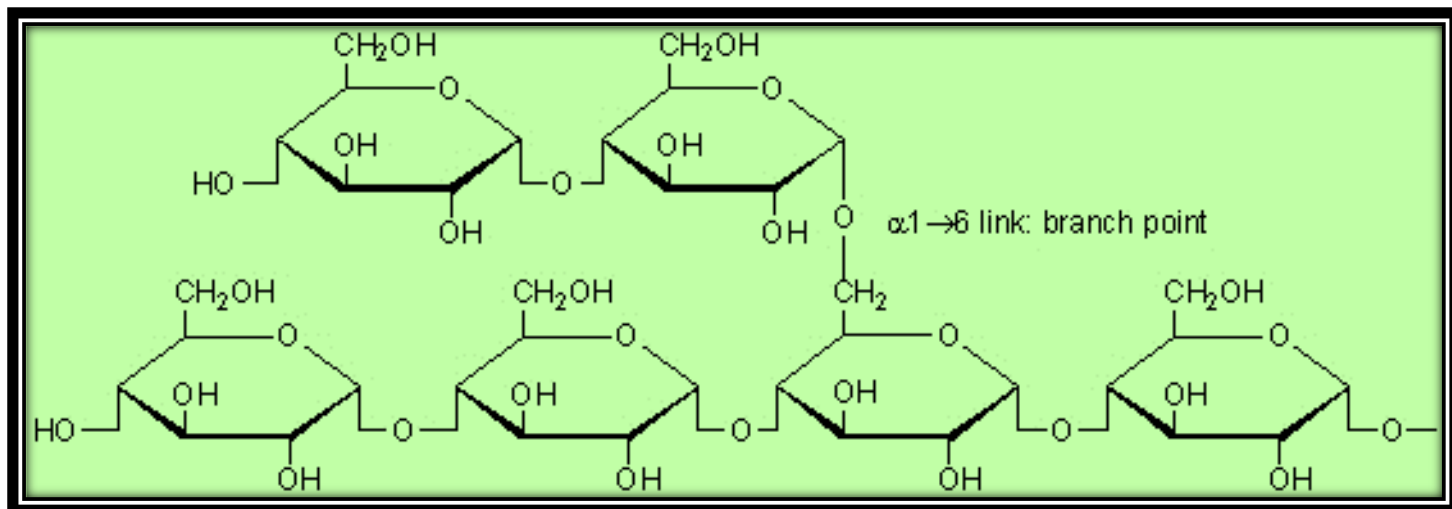
Thus, the main thing you need to understand is that this cycle takes acetyl-CoA into succinate for the synthesis of carbohydrate...

Glycogen

Is a very large branched polymer of glucose and the storage form of glucose. It is found mainly in the **liver** and **skeletal muscle**.

Most glucose residues are the α -1,4- glycosidic bonds which I will show momentarily.

Branches are seen by α -1,6-glycosidic bonds of which there is one in about ten residues.



Branching:

- 1) Makes polymers more compact
- 2) Makes polymers more H₂O soluble
- 3) Produces more terminal glucose residues

Glycogenolysis is the breakdown of glycogen. We see the release of glucose in the liver due to low levels of glucose into glucose-6-phosphate, which is then made into glucose. This helps to raise the glucose levels in the blood.

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In muscle, the glucose-6-phosphate enters glycolysis directly rather than being delivered to the blood.

We need not know any big biochemistry reactions, only these concepts.

Glycogen is synthesized from glucose-6-phosphate and stored within the liver and skeletal muscle as glycogen granules. We need not go into any details here, just the concept.

For those wanting to explore this a bit more, join my DAT Destroyer Study Group on Facebook, and we can chat! Even though I will never meet many of you, this is the next best thing.

Amino Acids

Let's finally talk about the excess of amino acids that are not going on to make proteins. Fatty acids can be stored as fat, glucose can be stored as glycogen, but amino acids **cannot be stored**. Surplus amino acids cannot be stored. Surplus amino acids are used as metabolic fuel.

Amino acids have their amino group, NH_2 removed in a process called **deamination** and used to form urea, but their carbon skeletons can make:

- A) Acetyl CoA
- B) Acetoacetyl CoA
- C) Pyruvate
- D) TCA cycle intermediates

Thus, I hope you can see that fatty acids, ketone bodies, and even glucose can be made from amino acids.

For example, several amino acids such as serine, alanine, threonine, and cysteine are made into pyruvate. Other amino acids like proline and glutamine are made into α -ketoglutarate, which is a TCA cycle intermediate.

Again, no need to memorize this, I just want you to understand the concept.

Mutations can lead to deficiencies in enzymes that catalyze amino acid metabolism. Consider a pathology called **Phenylketouria** (PKU).

Normally, phenylalanine is made into an amino acid called tyrosine. However, the enzyme in this disease is missing. Levels of phenylalanine build up in the blood and urine. Mental retardation can result. I have read that 1% of patients in mental institutions have this disease. Brain weight is below normal, myelination of nerves is defective as well.

Read about PKU disease as practice for the reading section. I will surely have it posted in our study group.

Fatty Acid Oxidation

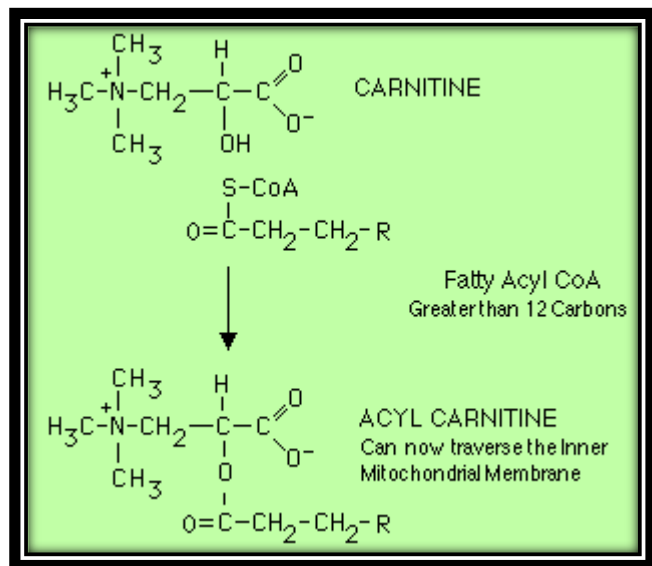
Fatty acids can be oxidized to yield large quantities of ATP.

Fatty Acid oxidation (Beta oxidation) occurs in the **mitochondrial matrix**.

I will spare you all the many different steps, but I do want you to know the result.

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Fatty acids are “activated” on the outer mitochondrial membrane and oxidized in the matrix of the mitochondria. “Activated” fatty acids are carried across the mitochondria membrane by a molecule called carnitine.



No need for further details. However, the molecule ends up giving us Acetyl CoA.

As you know, the Acetyl CoA can now enter the TCA cycle.

An 18-carbon fatty acid gives 9 Acetyl CoA. In addition to Acetyl CoA, NADH and FADH₂ are also made. These electron carriers can also furnish ATP. Fatty acid oxidation also gives metabolic water, which is a nice source of water if you are a camel living in the desert.

Fatty Acid Synthesis

Occurs in the **cytosol**

Fatty acids are made from Acetyl CoA (What a huge player Acetyl CoA is!!)

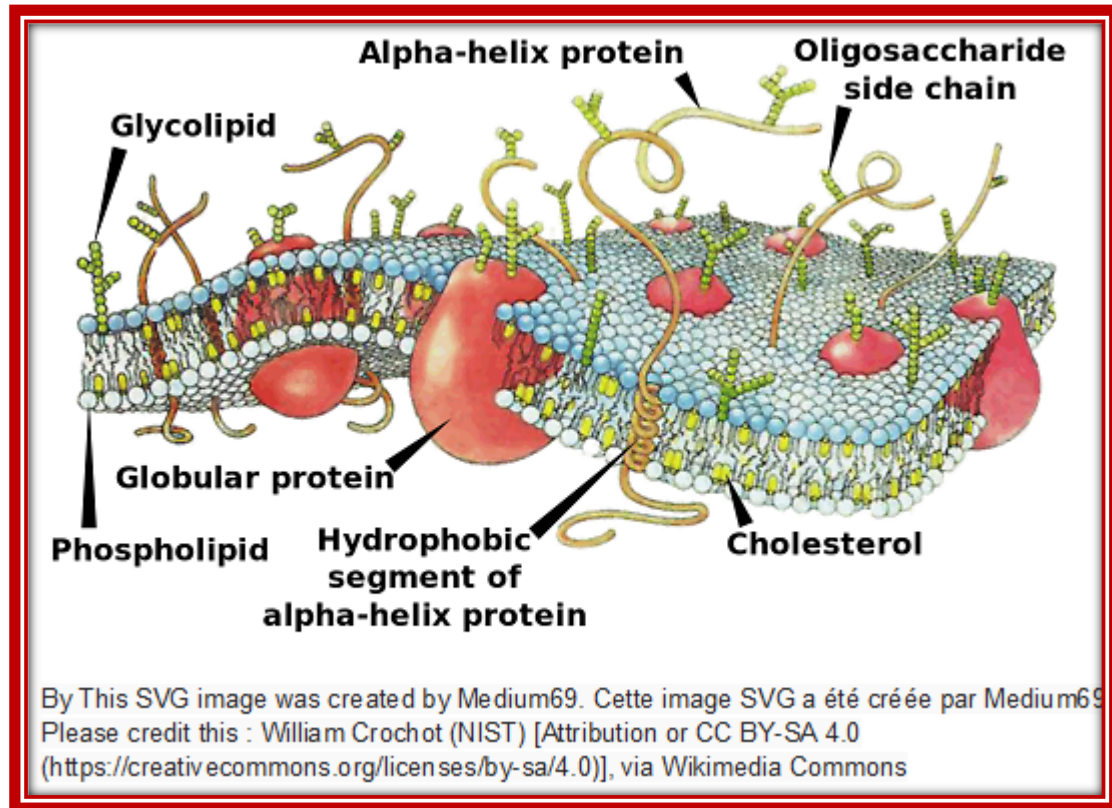
Free fatty acids do not occur in the cell to any great extent, but are found incorporated into triglycerides and phosphotriglycerides.

Different enzymes and coenzymes are used in fatty acid synthesis than seen in fatty acid oxidation.

I think this will be fine for the DAT exam. In biochemistry, you will learn the pathways for oxidation and synthesis.

Chapter 3 - Metabolism

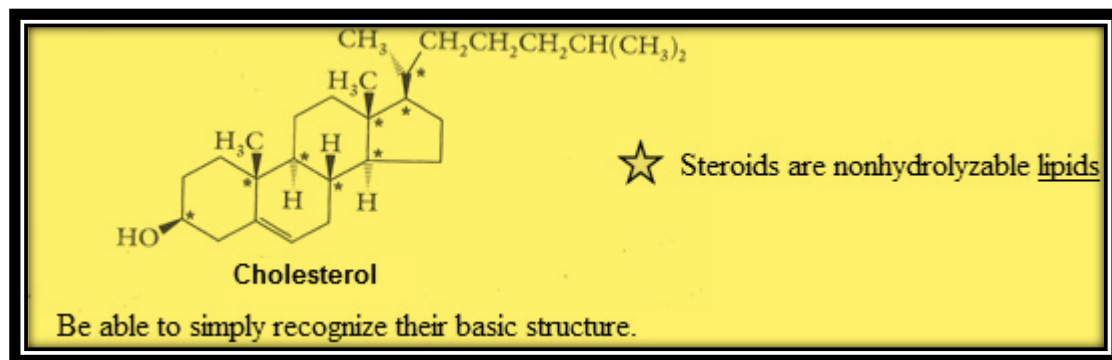
Cholesterol



Cholesterol is synthesized from Acetyl CoA.

This steroid modulates the **fluidity** of eukaryotic cell membranes. Cholesterol is the precursor of steroid hormones like cortisol, progesterone, testosterone, and estradiol.

Here is cholesterol... I starred the chiral carbons for you... great practice for Organic Chemistry.



Plants contains very little cholesterol, but it is the major steroid in animals.

It has 8 chiral carbons, thus $2^8 = 256$ stereoisomers (128 pairs of enantiomers).

★ The **liver** is the principle site for the synthesis of cholesterol.

Chapter 3 - Metabolism

Cholesterol is also involved in the synthesis of **bile acids** which are in the bile and assist in the absorption of dietary lipids in the intestine. Bile acids are often deprotonated becoming the **bile salts**. They also **emulsify** fats.

Cholesterol has been called a Janus-faced molecule. I want you to all look up that vocabulary word!

This useful cholesterol molecule can also be lethal. When the cholesterol percentage in bile gets too high, precipitation occurs to form **gallstones**. If a blockage occurs, bile cannot enter the duodenum, hence the ability to digest fats is lost. Bile pigments enter the blood and the skin becomes yellow- a condition called **jaundice**.

This pigment found in bile is called **bilirubin**. High cholesterol is also associated with heart disease.

Bilirubin is excreted in bile and urine and is the main cause of jaundice, and gives color to bile and stool.

Bilirubin can be “conjugated” with a molecule of glucuronic acid which makes it more water soluble. The “conjugated” form is the main form of bilirubin present.

Very recently bilirubin has been shown to possess important functions as an antioxidant.

The Urea Cycle

This is a central pathway in **nitrogen metabolism**. This cycle is involved with both the catabolism and anabolism of amino acids is linked to the Krebs Cycle (TCA cycle).

In most terrestrial vertebrates, NH_4^+ is made into **urea** and the excreted. Highly toxic NH_3 must have a means to be excreted. This cycle occurs mainly in the **liver**, and to a smaller extent, the kidney. The urea made by the liver, is released into the blood where it is destined for the kidney to be excreted.

We need not go into all the reactions, as you will reserve this for your Biochemistry class.

I would like you to at least understand, that before the urea cycle occurs, NH_3 is made into a compound called carbamoylphosphate and requires 2 ATP molecules.

This cycle requires ATP, it does not produce ATP. **This is an important point to remember.**

Several enzymatic reactions occur:

- a) One is a mitochondrial reaction
- b) Others are cytosolic reactions

Fumarate is produced in this cycle and is also an intermediate in the TCA cycle, and is returned to that cycle.

Inherited disorders can interfere with this cycle resulting in elevated NH_4^+ (hyperammonemia).

Coma and death result shortly after birth if the urea cycle does not run correctly. High NH_4^+ levels can also cause brain damage. **This will suffice for the DAT.**

Let's just review the needed nitrogenous wastes:

- 1. Terrestrial animals and mature amphibians: Urea
- 2. Fish and Marine organisms: Ammonia

Chapter 3 - Metabolism

3. Reptiles, Birds, and, Insects: Uric Acid

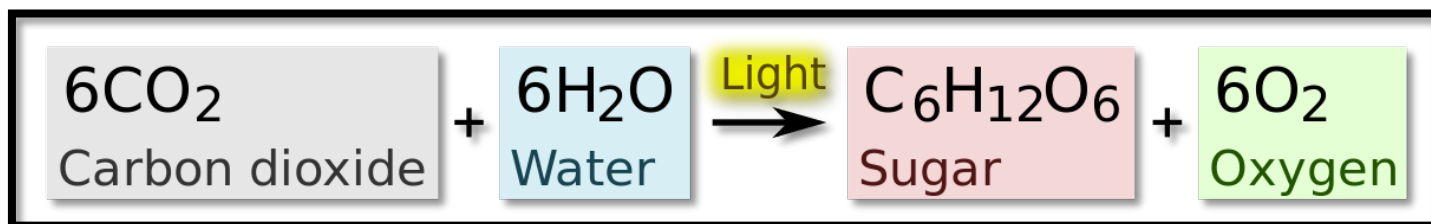
Amphibians (frog, toad, salamander, newt)

Reptiles (snake, crocodile, alligator, turtle)

Photosynthesis

We make sugar and O₂!!

The DAT will not ask great details here, so I will touch it briefly!



Chlorophyll is the green pigment located in the chloroplasts which absorbs light energy that is needed to initiate this process.

Chlorophyll resides in the **thylakoid membranes**.

Two main processes... we don't need too much detail here, just the basics!!

Light Reaction: uses light for ATP production

Dark Reaction: sugar making!!

Photosynthetic pigments which absorb the light are chlorophylls and carotenoids.

Light Reaction Highlights

ATP, O₂, and NADPH are made

Occur in the **grana** (membranous bodies stacked within the chloroplast)

H₂O is split by sunlight releasing the O₂. [This is an oxidative process].

Dark Reaction Highlights

Known as the **Calvin-Benson Cycle**

Carbon dioxide, enters the stomates to produce the 3 carbon PGAL.

A reduction reaction known as "**carbon fixation**" occurs

Carbon fixation occurs in the **stroma**

The main enzyme here is called **Rubisco** which is the most abundant protein in nature.

Chapter 3 - Metabolism

After many many reactions, 6 molecules of CO₂ produce one molecule of glucose.

Six turns of the cycle occur

Photosynthesis has an efficiency of about 30%.

This process is vital to life on Earth, for it gives O₂ to our planet.

In the chloroplast, like the mitochondria, redox reaction occurs in which a H⁺ gradient is formed across a membrane, ATPase is used to form ATP!!

Chloroplasts and mitochondria: **Endosymbionts!**

Theory suggests that these two organelles were once upon a time, small prokaryotic organisms that began to live inside larger cells!

Two possible paths for electrons to follow:

- A) Noncyclic Photophosphorylation
- B) Cyclic Photophosphorylation

Noncyclic photophosphorylation involves electrons that enter two electron transport chains to produce ATP and NADPH. ATP is made by the same process we saw in the mitochondria.... By chemiosmosis. This ATP synthesis reaction is fruitful because of **light**.

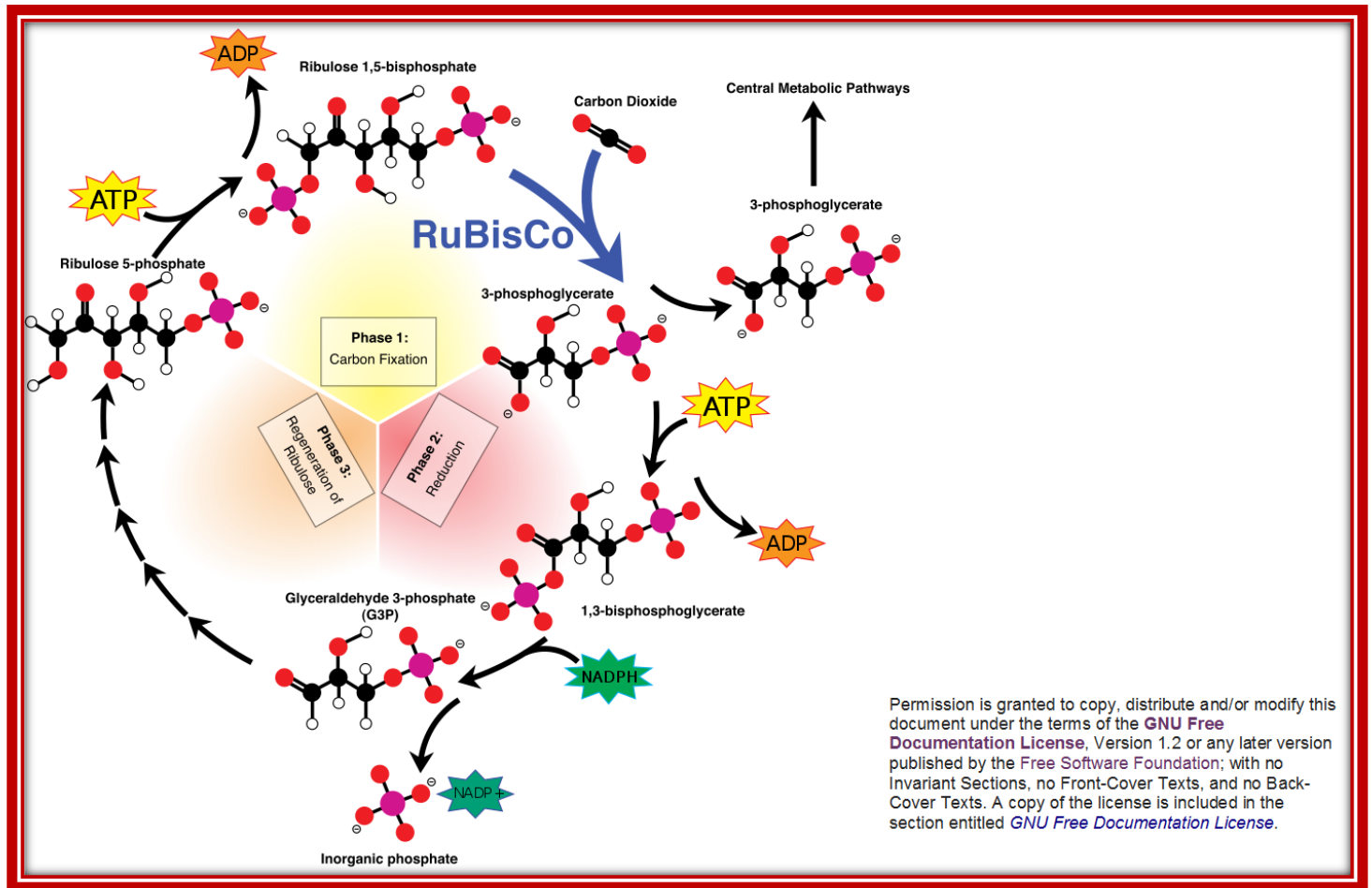
The NADPH produced in this noncyclic photophosphorylation is shuttled to the **Calvin Cycle**. This cycle consumes quite a bit of ATP, so more is needed. When more is needed, we have **cyclic photophosphorylation**. This cycle produces ATP only!

Chapter 3 - Metabolism

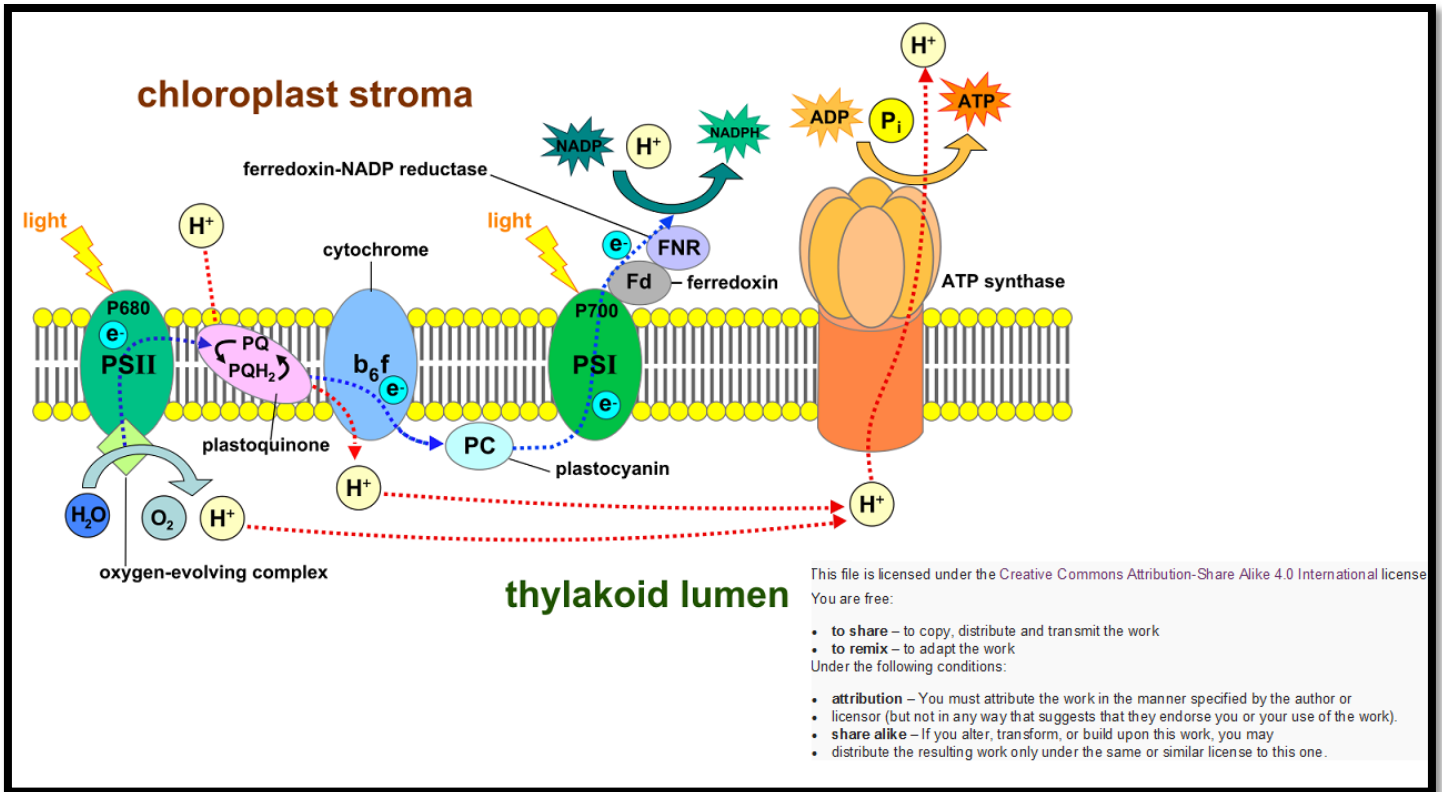
Thus, Calvin-Benson Cycle:

- a) Carbon fixation occurs here... sugar making
- b) ATP is used
- c) 6 turns
- d) NADPH is oxidized
- e) Rubisco is regenerated, this is needed to capture the carbon in the first place

CO₂ is attached to Rubisco at the very start... this attachment produces very unstable intermediate that splits into 2 molecules of phosphoglycerate.

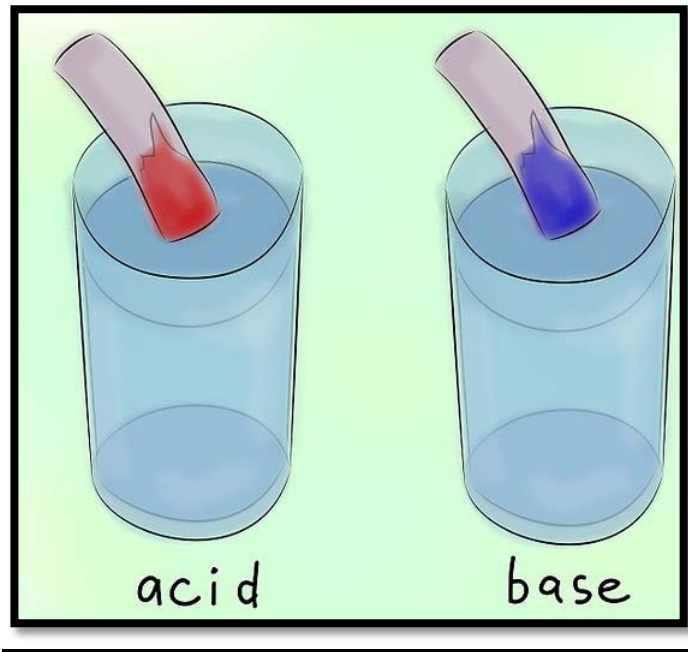


Chapter 3 - Metabolism



Chapter 4 - Acid-Base Balance

Acid-Base Balance



Blood pH is approximately **7.4**.

Normally, we see a range of 7.35-7.45.

Below 7.35 = Acidosis

Above 7.45 = Alkalosis

In **Acidosis**, we see a depression of CNS synaptic transmission. Disorientation and coma can result. Death soon follows.

In **Alkalosis**, we see hyperexcitability in CNS and PNS with extreme nervousness and spasm of muscle. Death can result if untreated.

The pH balance can be easily upset. CO₂, lactic acid, ketone bodies, etc. can all contribute to lowering the blood pH.

Three main mechanisms can help maintain pH:

- 1) Buffers
- 2) CO₂ removal by the lungs
- 3) H⁺ removal by the kidneys

Chapter 4 - Acid-Base Balance

Buffer

A buffer helps maintain pH. Buffers can release or gain H^+ . If a small amount of OH^- ions are introduced into a buffer solution, the conjugate acid will react with it. If a small amount of hydronium ion is added, the conjugate base reacts with it. These buffers act as “sponges”.

pH can be calculated by using the **Henderson-Hasselbach equation**:

$$pH = pK_a + \text{Log} \frac{[\text{base}]}{[\text{acid}]}$$

For example:

The pK_a of Acetic Acid is 4.7. If we have 0.005M Acetic Acid and 0.003 M sodium acetate, find the pH.

$$pH = pK_a + \text{Log} \frac{[\text{sodium acetate}]}{[\text{acetic acid}]}$$

$$pH = pK_a + \text{Log} \frac{[0.003]}{[0.005]}$$

$$pH = 4.7 - .22$$

$$pH = 4.48$$

You will learn more about buffers in the DAT Destroyer. I have written up several for you to practice. If you have a tough time with this, feel free to ask me personally on the DAT Destroyer Study Group page on Facebook.

In all aspects of metabolism and cellular activities, control of pH of the cells and body fluids is of great importance. Enzymes show maximum activity at a characteristic pH, thus on either side of the optimum pH their catalytic activity will decrease markedly.

Remember... the pH is a log scale.

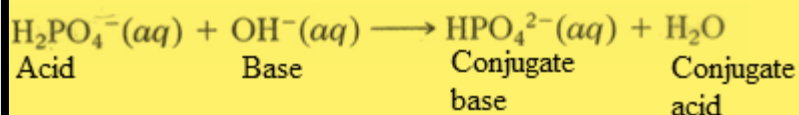
Thus, if the pH of the stomach was about 2 and the pH of the small intestine was about 8, how much more acidic is the stomach than the small intestine?

$\Delta pH = 8 - 2 = 6$... Each pH unit is a factor of 10... thus the stomach is 1×10^6 times more acidic than the small intestine.

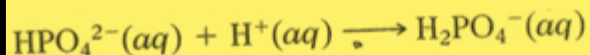
The principle **intracellular buffer** is the phosphate buffer.

Chapter 4 - Acid-Base Balance

HO^- ions are neutralized as follows:



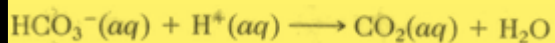
H^+ ions are neutralized as follows:



The principle blood buffer is **bicarbonate**.



and



Acidosis and Alkalosis can be classified as respiratory or metabolic. Let us review:

Chapter 4 - Acid-Base Balance

Respiratory Alkalosis

pH > 7.45

Loss of CO₂ occurs... **hyperventilation!!**

When CO₂ levels increase, the respiratory center in the brain tells you to breath more rapidly.

This happens in cases of severe anxiety, early stages of aspirin overdose, or O₂ deficiency in high altitude. (The rising CO₂ and H⁺ ions are sensed by chemoreceptors in the carotid artery and the brain receives the message).

Respiratory Acidosis

pH < 7.35

Here we interfere with H⁺ loss.

People with Emphysema will **hypoventilate** and the CO₂ loss is hindered. If CO₂ is not removed from the lungs fast enough, it “backs up” and H⁺ will not be removed by HCO₃⁻.

Airway obstruction, or if a drug is given that depresses the respiratory center, we could likely see respiratory acidosis. A barbiturate is such a drug! Asthma or Pneumonia too!

Read 1 and 2 over a few times until you understand it. As a future doctor, you will encounter this often!!

Metabolic Acidosis

pH < 7.35

This may be due to loss of HCO₃⁻ ions through kidney dysfunction or severe diarrhea. Laxative abuse as well.

Accumulation of metabolic acids such as seen in diabetes mellitus... think ketone bodies!

Coma and death could result. If your kidneys are not working properly, H⁺ are not effectively removed, thus, we have an abundance of H⁺ ions.

Metabolic Alkalosis

pH > 7.45

This occurs when loss of acids is seen. Repeated vomiting of the gastric contents, or if you take too much antacid. The respiratory system tries to compensate by hypoventilation, you retain CO₂ in the body, and this will lower the pH.

Hopefully, you can see that the blood, lungs, and kidneys all work as a team to maintain the proper pH to maintain homeostasis. pH management involves an intricate interplay of chemical and physiological events that must be carefully controlled by the marvel called the human body.

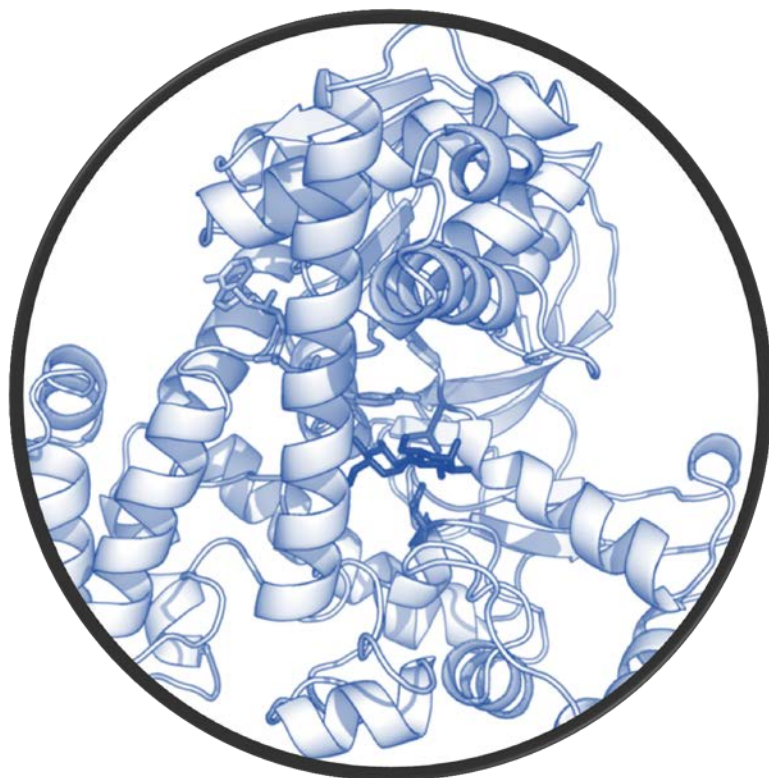
Chapter 5 - Enzymes

Enzymes

Let us now discuss enzymes, **a very important topic for your exam!**

Most enzymes are protein in nature and function as biological catalysts.

Here is a picture... note that they are macromolecules with great complexity.



They act as catalysts (**lower the energy of activation**).

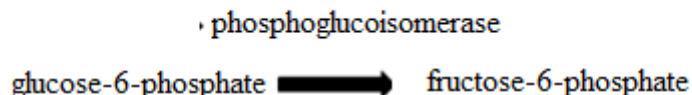
Many end in “ase” such as lipase, lactate dehydrogenase, but not all. Trypsin, chymotrypsin (pancreatic enzymes that degrade proteins) and pepsin (stomach enzyme for protein digestion) are examples that do not end in “ase”.

Six Major Classes

1) Isomerases: transfer of groups within a given molecule

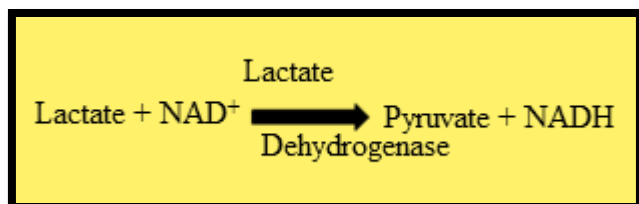
For example:

Chapter 5 - Enzymes



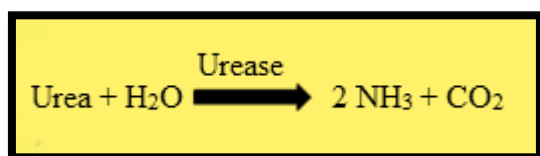
2) Oxidoreductase: catalyze redox reaction; look for the word dehydrogenase and NADH or FADH₂!!

For example:



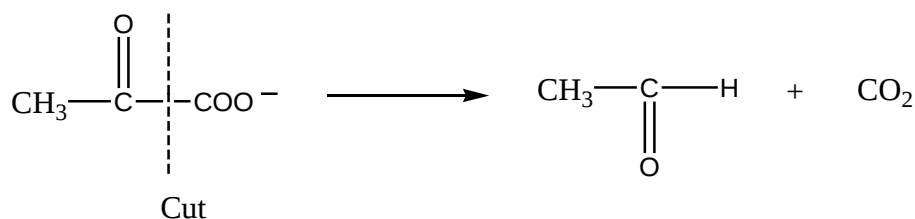
3) Hydrolases: cuts bonds by using H₂O

For example:



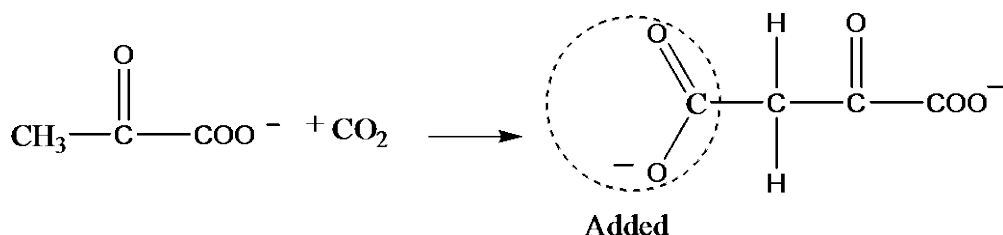
4) Lyases: cuts C-C, C-S, and some C-N bonds.

For example:



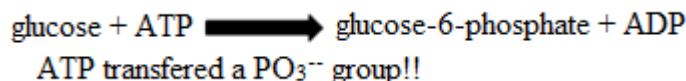
5) Ligases: catalyzes formation of bonds like C-O, C-N, C-C and C-S.

For example:



Chapter 5 - Enzymes

6) **Transferases**: catalyzes group transfer



★ A trivial name of kinase is more commonly used here.

Structure

Remember, enzymes are proteins:

Protein structure is discussed at four levels:

Primary structure is the α -amino acid sequence of a polypeptide.

Secondary structure is the conformation in a local region of a polypeptide molecule. The conformations are the same in different regions of the molecule for some polypeptides but are different in different regions for other polypeptides.

Tertiary structure exists when the polypeptide has different secondary structures in different local regions. Tertiary structure describes the three-dimensional relation among the different secondary structures in different regions.

Quaternary structure exists only in proteins in which two or more polypeptide molecules aggregate together. It describes the three-dimensional relation among the different polypeptides.

Enzymes contain a specialized “pocket” called the **active site**. This active site contains amino acids, ions, and groups that take part in substrate binding.

Turnover #: number of substrate molecules making product. **Turnover # = K_{cat}**

Enzymatically controlled reactions are about 1×10^3 to 1×10^9 times faster than without a catalyst!

Enzymes work by **specificity of fit and charge**.

Holoenzyme: the active enzyme including the nonprotein portion

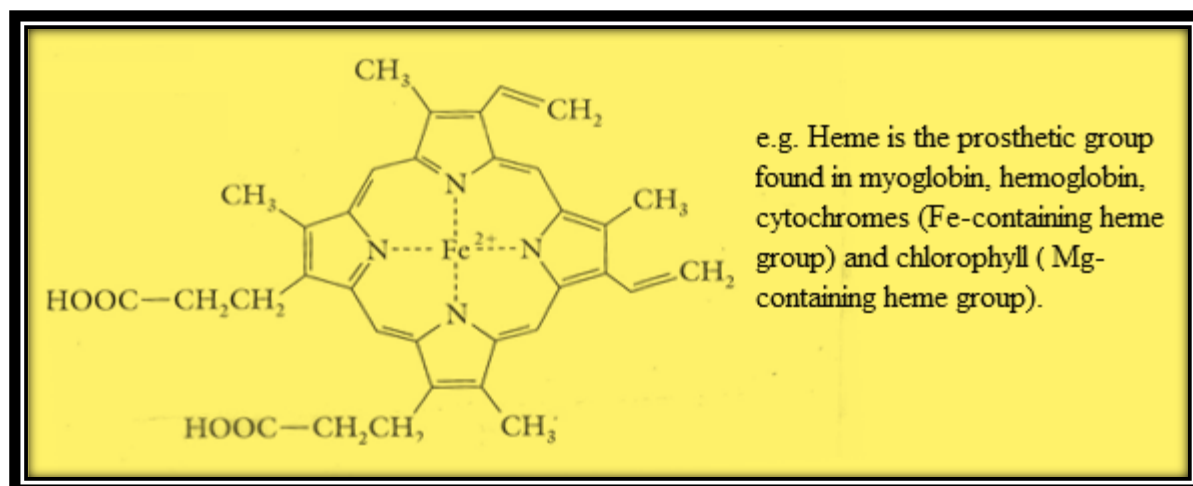
Apoenzyme: inactive enzyme-does not contain the nonprotein portion

If the nonprotein portion is an ion such as Zn^{+2} or Fe^{+2} we call it a **cofactor**.

If it is a small organic molecule it is a **coenzyme**.

If the coenzyme is permanently bound to the enzyme and returned to its original form after a reaction is completed, we call it a **prosthetic group**.

Chapter 5 - Enzymes



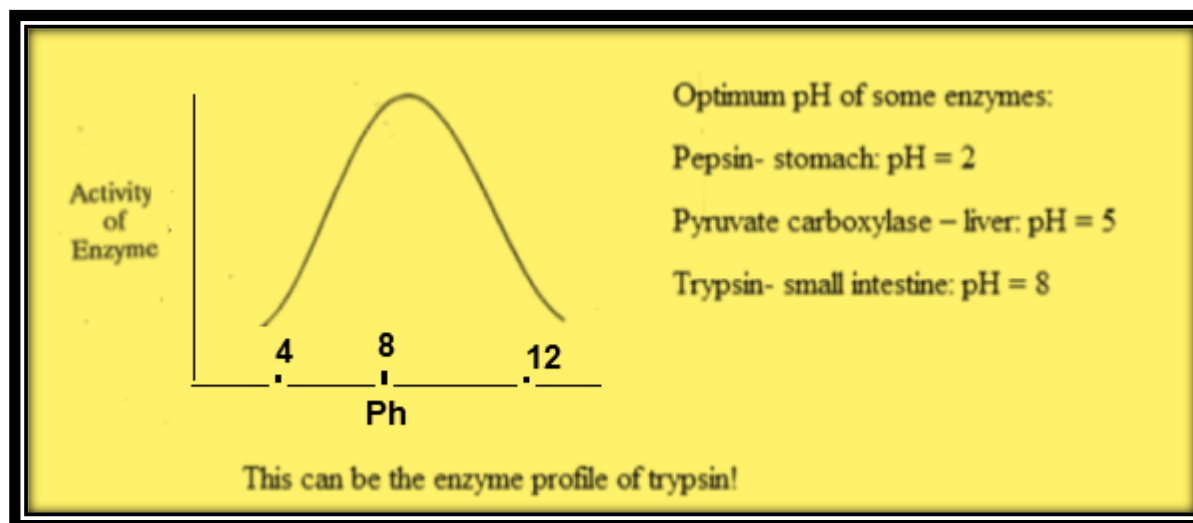
The enzyme allows a reaction to occur by providing an alternative reaction pathway that lowers the energy of activation.

★ **Enzymes do not change:**

Equilibrium, ΔG , ΔH , K_{eq} constant, or product amount

Optimum Conditions

Enzymes display **optimum pH** at which its activity is at a maximum.

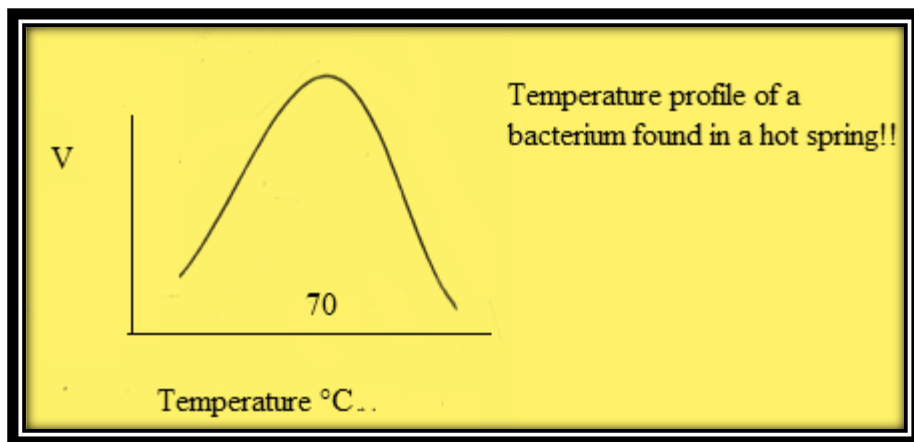


Optimum temperature

For most human enzymes 37°C is best.

Over 40°C human enzymes begin to denature (lose 2°, 3°, 4° structures).

Chapter 5 - Enzymes



If you add H^+ (acidify) or ADD OH^- (make alkaline) critical groups can become protonated or deprotonated... (NH_3^+ or COOH could be deprotonated... NH_2 or COO^-).

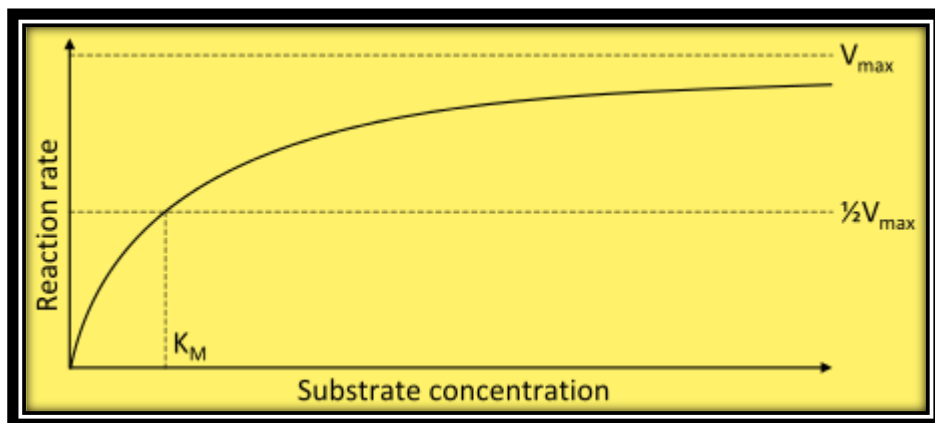
This change can interfere with binding and decrease reaction rate!

Michaelis-Menten Kinetics

Most enzymes follow what is called **Michaelis-Menten Kinetics**.

Remember: When enzyme becomes saturated with substrate all the available binding sites on the enzyme are taken up.

Let us examine the hyperbolic curve that shows Michaelis-Menten Kinetics:



As shown on the graph above, it has been observed that:

At relatively low S concentration, V_0 , the rate of the reaction is directly proportional to S concentration. There is a linear relationship between the rate and the S concentration. The reaction is **1st order** in this part of the graph.

At higher concentrations of S, you deviate from 1st order and obtain what is termed **mixed order** kinetics. The reaction rate still depends on S concentration, but there is not a linear relationship between the two.

Chapter 5 - Enzymes

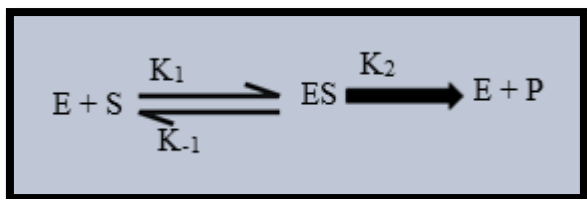
Eventually, as S concentration increases, the rate becomes constant. At this point, all enzyme molecules have S bound at their active sites, and the rate of reaction is independent of S concentration. Rate now depends on E concentration. (The only way you can increase the rate is to add more enzyme). You now have **zero order** kinetics.

K_m is the Michaelis constant and reflects the affinity of the enzyme for its substrate.

K_m = substrate concentration that allows us to achieve $\frac{1}{2} V_{max}$ value!!

Small K_m : high affinity of enzyme for substrate. Why? Only a small [S] is needed to half-saturate the enzyme and get it to $\frac{1}{2} V_{max}$!!

Large K_m : Low affinity for substrate... a high concentration would be needed to allow us to achieve $\frac{1}{2} V_{max}$.



ES represents the **enzyme-substrate complex**. We assume that [ES] does not change with time. i.e. Rate of formation of [ES] = Rate of breakdown

Further details of this will be presented in the General Biochemistry class.

The best parameter for “catalytic efficiency” is the K_{cat}/K_m ratio.

K_{cat}/K_m = efficiency

We want a big K_{cat} and a small K_m to be highly efficient!

Penicillinase has a K_m of 0.05 mM and lysozyme has a K_m of 0.006 mM. However, penicillinase is considered the more efficient enzyme. Explain why this conclusion at first seems odd, and tell how it can be justified. Be sure to consider the physical significance of the enzyme parameters.

A small K_m means that less substrate is needed for the enzyme to reach a rate of $\frac{1}{2} V_{max}$. The small value therefore implies that lysozyme is the better enzyme. However, you must also consider K_{cat} , turnover number. If penicillinase has a much larger K_{cat} , that could be the overall more important factor and it could be the more efficient enzyme. Its second order rate constant (K_{cat}) could be larger.

Inhibitors of Enzymes

Competitive Inhibitor

Reversible

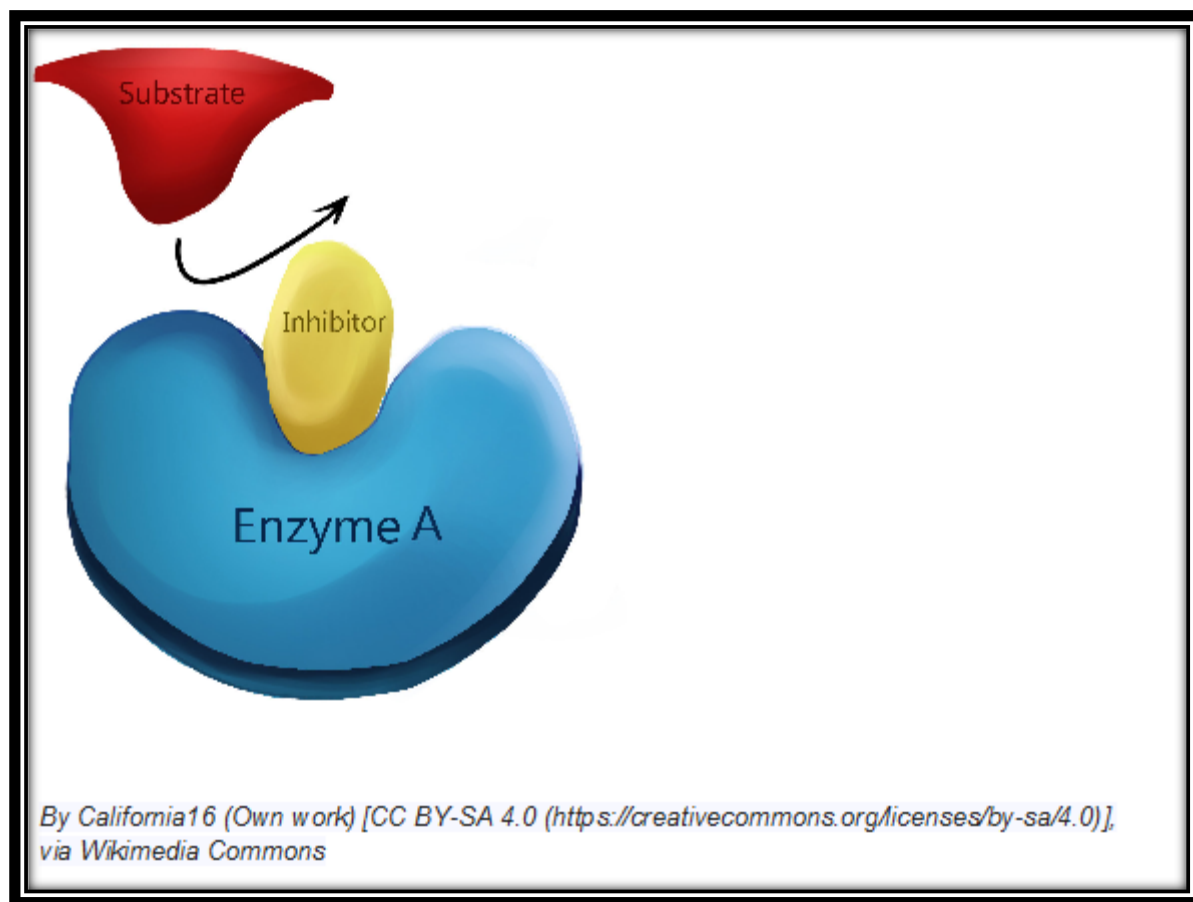
The inhibitor competes for the active site that the substrate normally binds...

V_{max} stays the same

Chapter 5 - Enzymes

Increasing [S] can help the situation and reverse the effect of the inhibitor.

e.g. statin drugs which are involved with lowering cholesterol inhibit a certain enzyme that makes cholesterol.



★ If you drink methanol, you might go blind. Alcohol dehydrogenases converts methanol into formaldehyde. If given ethanol, it will compete for the active site of the enzyme and methanol can be excreted harmlessly in the urine.

A competitive inhibitor will increase the “apparent” K_m for a given substrate since more [S] is needed to achieve $\frac{1}{2} V_{max}$.

Noncompetitive Inhibitor

Binds to a site distant from the active site. When this occurs, we **alter the conformation** of the enzyme!

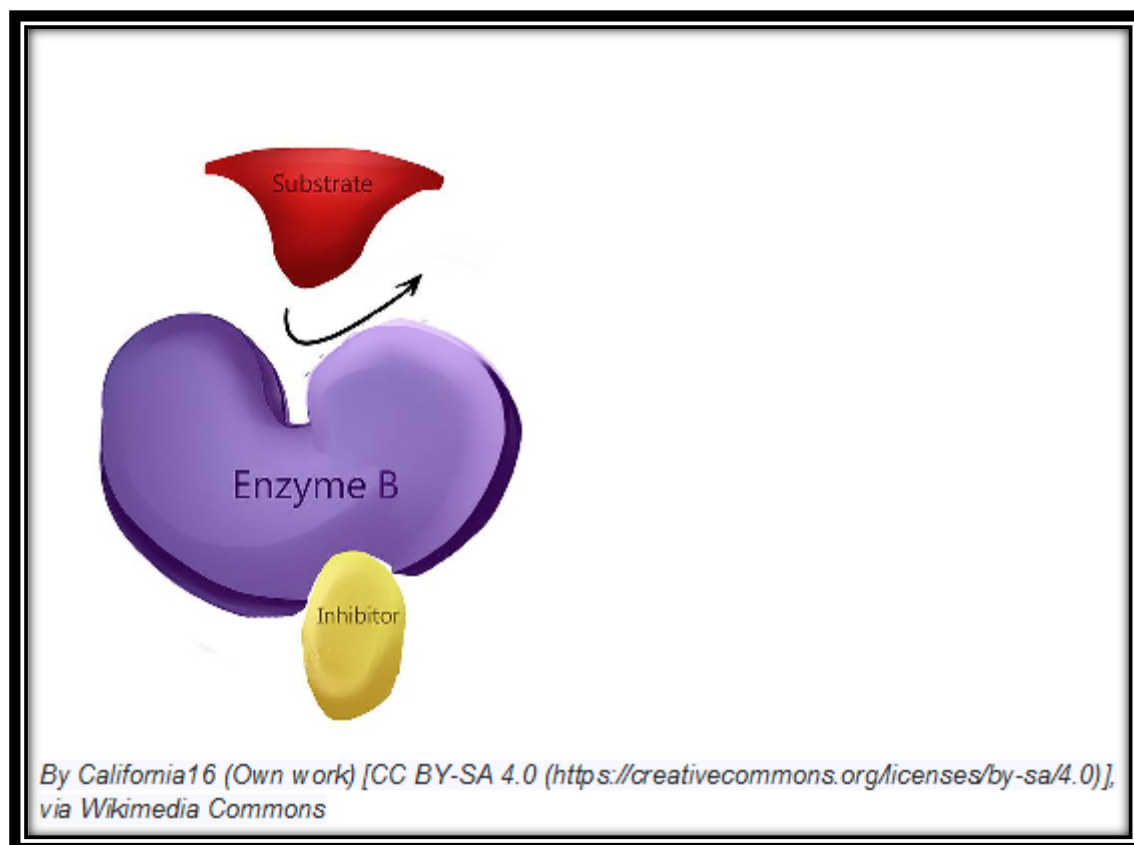
V_{max} decreases

K_m is unchanged ... it cannot be overcome by increasing [S].

e.g. Pb^{++} react with the SH group of cysteine in proteins.

Insecticides bind to acetylcholinesterase in a noncompetitive inhibitory fashion.

Chapter 5 - Enzymes



Uncompetitive Inhibitor

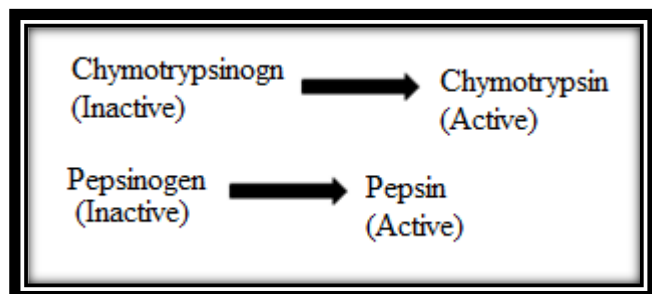
Binds to the [ES] complex

Binds at a site distinct from the active site.

Cannot be reversed by increasing [S]

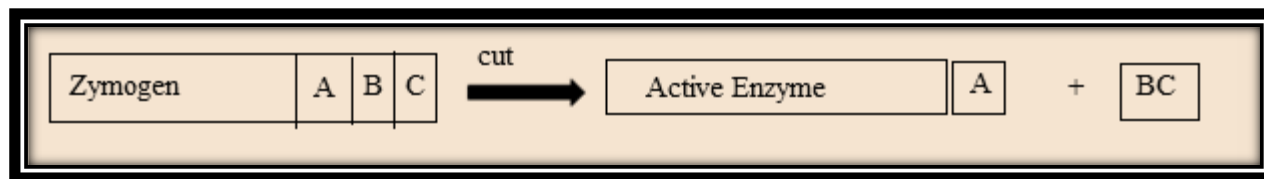
$V_{\max}$ is decreased

The inactive form of an enzyme = Zymogen.



★ Proteolytic cleavage can cause zymogen activation.

Chapter 5 - Enzymes



Cleavages can cause conformational changes that expose the enzyme active site.

Enzyme Denaturation

Enzymes can be denatured several ways, whereby we lose 2°, 3°, 4° structure.

(In digestion we lose 1°, 2°, 3°, 4°).

Temperature increase: disrupts bonding interactions

Radiation: disrupts native conformation

Mechanical Agitation: violent mixing as in using a blender, or shaking. Will cause polypeptide chains to unfold.

pH: causes groups to gain or lose charges, disrupts bonding interactions

Salts of heavy metals: Pb^{++} , Hg^{++} , Ag^+ in particular react with SH (sulfhydryl) groups and prevent the formation of native conformation.

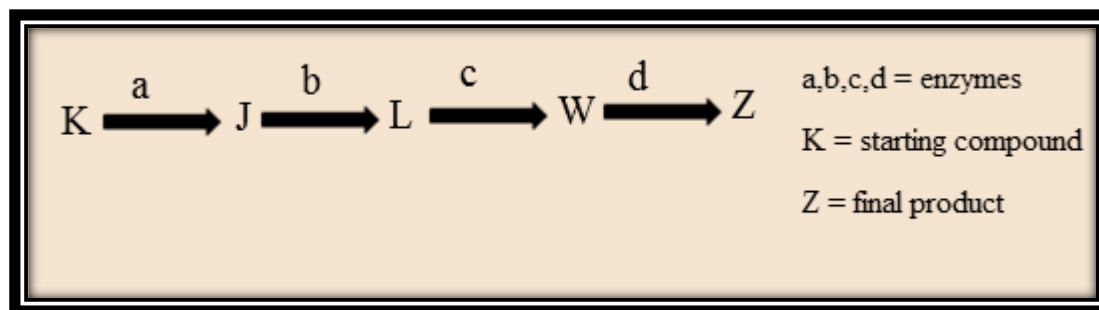
Organic solvents (soaps, detergents, urea, alcohol): disrupts bonding interactions such as hydrogen bonds (i.e. alcohol passes through the cell wall of bacteria and destroys proteins!)

Oxidizing and reducing agents: can form -S-S- bridges (oxidation) or destroy them by reduction.

★ Enzymes that catalyze the same reactions, but differ in subunit composition are called **isozymes**. Lactate dehydrogenase has 5 isozymes!! The isozyme composition in various tissues is determined by genetics. They may differ slightly in V_{max} and K_m values.

Control of Enzyme Activity

Let us consider one type... **feedback inhibition**.



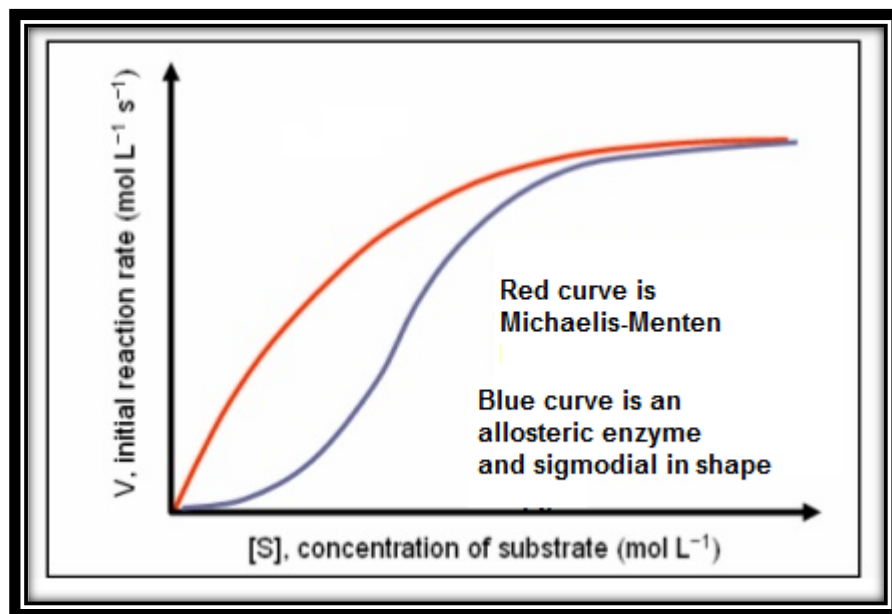
The final product is often formed in reasonably high concentrations, and will combine specifically with the first enzyme, a, of this reaction pathway. This is an example of a feedback inhibition.

Chapter 5 - Enzymes

What is an allosteric enzyme?

This is the type of enzyme that undergoes a conformational change and functional change when binding to specific molecules called activators or inhibitors.

Allosteric enzymes do not follow the hyperbolic curve as we saw with the Michaelis-Menton enzymes, but follow a **sigmoidal curve**.



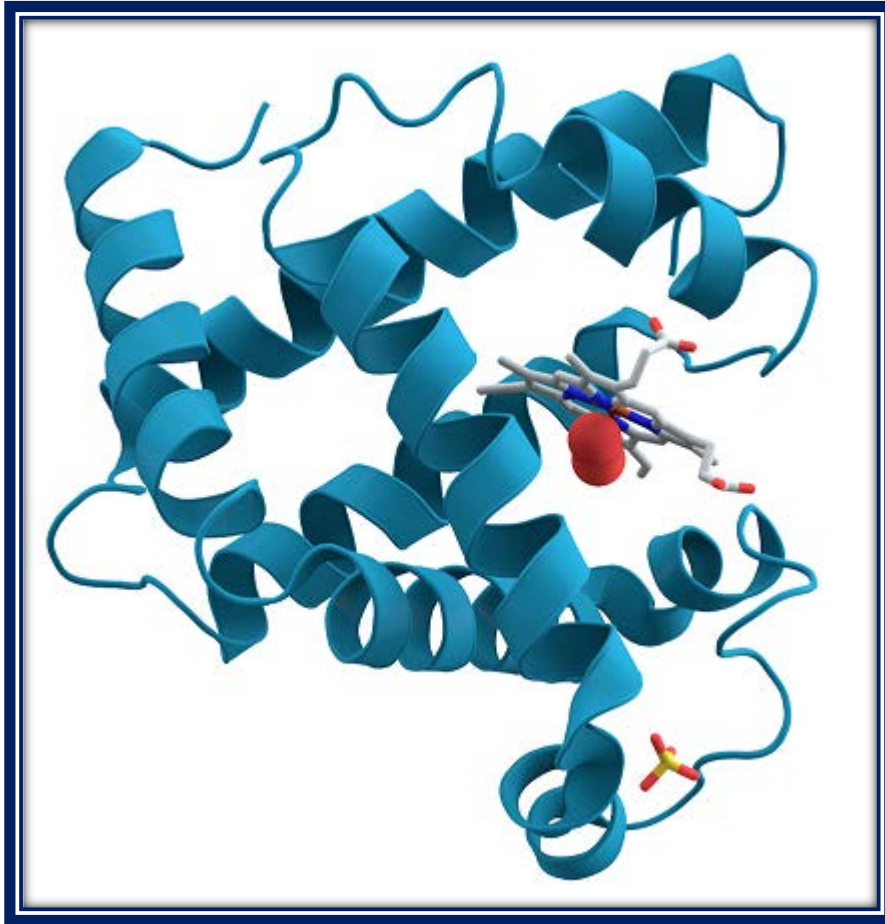
e.g. When 2,3-BPG binds to an allosteric site on Hemoglobin, the O₂ affinity decreases.

In allosteric regulation we “control” the enzyme by binding an effector molecule at a site other than the enzyme’s active site.

Chapter 6 - Myoglobin and Hemoglobin

Myoglobin and Hemoglobin

Myoglobin



A globular protein that is found in skeletal muscle and cardiac muscle in almost all vertebrates and mammals.

Has a higher O_2 affinity than hemoglobin.

Stores O_2 and uses it as a reserve for when the demand for O_2 cannot be adequately met by Hb.

High amounts of myoglobin allow organism to hold their breath for an extended time under water... think whales and seals!! **This is a favorite DAT-type question!!**

O_2 is bound on a heme group found on its single polypeptide chain.

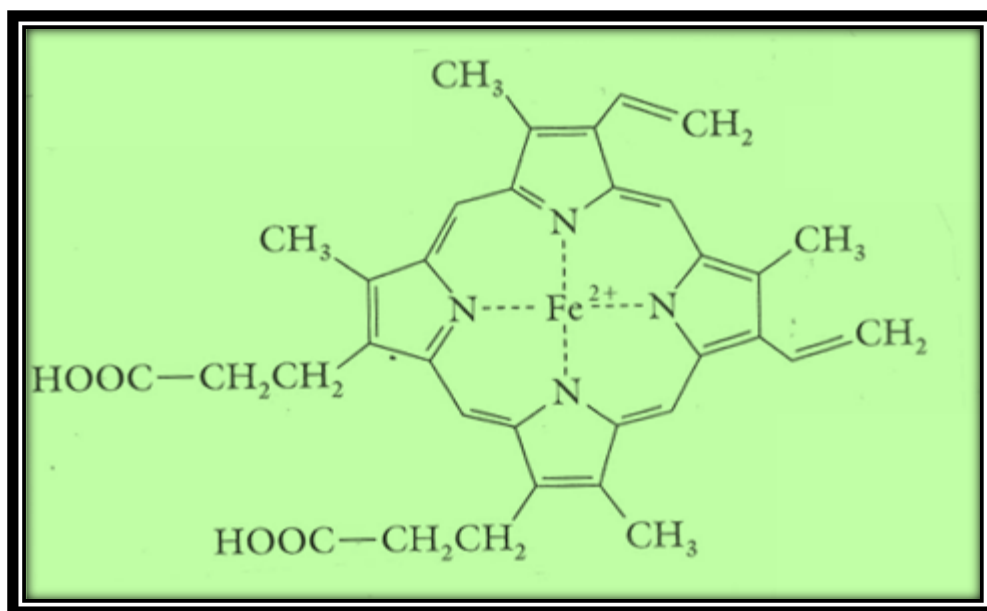
Most of the molecule is α -helix (80%). Since it is a monomer of 1 chain, it has no quaternary structure.

The folding of the myoglobin (Mb) chain places the nonpolar residues on the interior, where they are shielded from water. Many polar amino acid residues reside on the outside, making Hb a H_2O -soluble globular protein.

Remember: globular proteins = hydrophilic and H_2O soluble

The heme group (prosthetic group... nonprotein part) sits on a crevice lined by nonpolar amino acids.

Chapter 6 - Myoglobin and Hemoglobin



This is heme:

X-Ray Crystallography clearly showed the 3D structure of this molecule.

Myoglobin is the heme iron containing protein responsible for the color of meat. The more myoglobin... the darker red the meat!! Older animals have more Mb... thus the meat is darker.

★ When a muscle is injured, heart or skeletal myoglobin is released into the blood. Within 2-3 hours, Mb levels in the blood rise after heart or skeletal muscle injury. At about 10 hours after injury, Mb levels peak. Mb can also appear in the urine after muscle injury.

Mb can bind only one molecule of O₂ since it contains one heme group.

Chapter 6 - Myoglobin and Hemoglobin

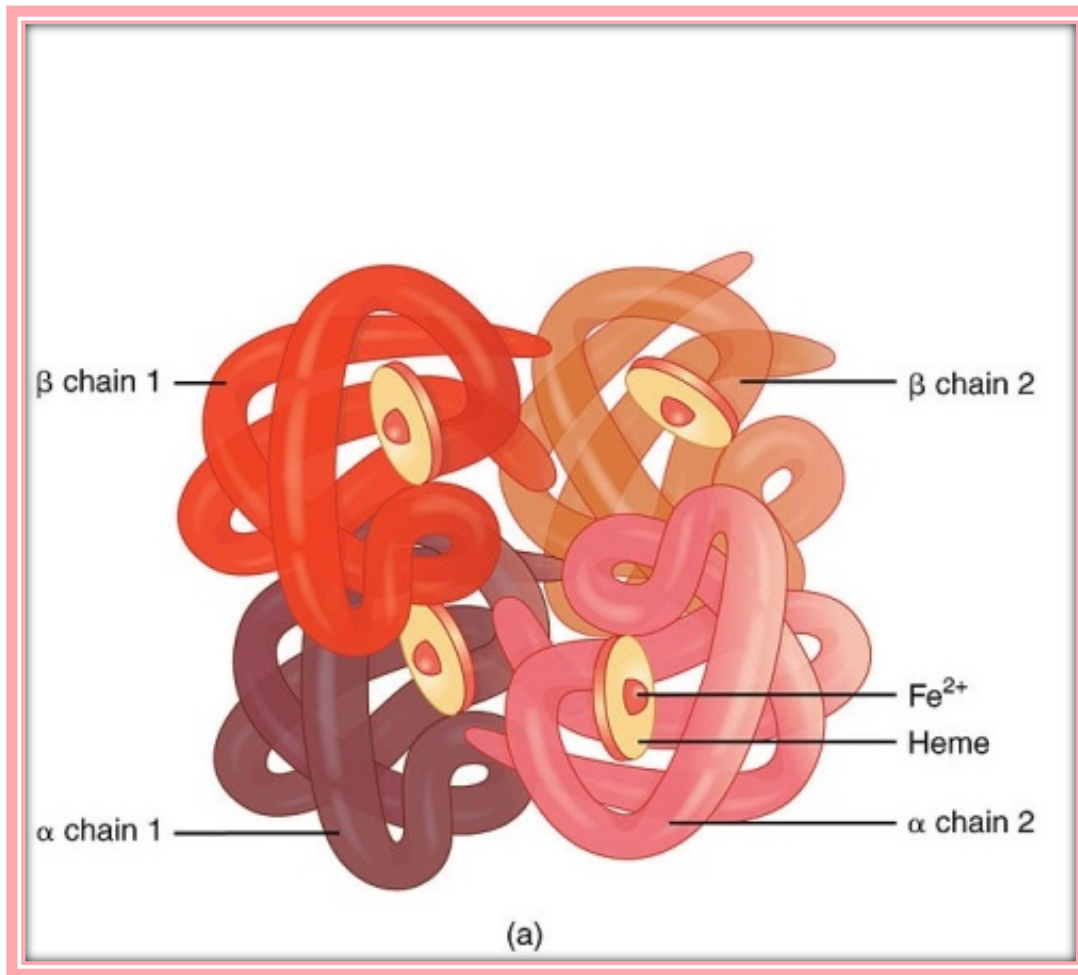
Hemoglobin (Hb)

A globular protein which has four polypeptide chains:

- a) 2 α -chains
- b) 2 β -chains

Similar 1°, 2°, and 3° structures to that of Mb. Each chain has a heme group with its Fe^{+2} ion.

When Hb is deoxygenated, a molecule called BPG is held in a central cavity.



This molecule is contained in red blood cells.

Hb can bind to other molecules besides O_2 :

HbO_2	OxyHb	Has oxygen bound
HbCO	Carboxyhemoglobin	Has carbon monoxide bound
HbCO_2	Carbaminohemoglobin	Has carbon dioxide bound

Chapter 6 - Myoglobin and Hemoglobin

Hb is found exclusively in red blood cells where its main job is to transport O_2 from the lungs to the tissue capillaries.

Since there are four hemes, this molecule can carry four O_2 molecules.

Unlike Mb which is a monomer of one chain, Hb is a tetramer and shows what is called **cooperative binding**.

What does this mean?

When an O_2 binds to Hb, many salt bridges are broken which causes the conformation to change. The binding of additional O_2 molecules becomes more easily attained. In other words, the affinity for O_2 binding is now enhanced. As you can see, Hb is an **allosteric protein**. The binding of O_2 to one subunit affects the other subunits.

Binding in myoglobin is not cooperative.

The cooperative binding of O_2 in Hb renders Hb a more efficient O_2 transporter.

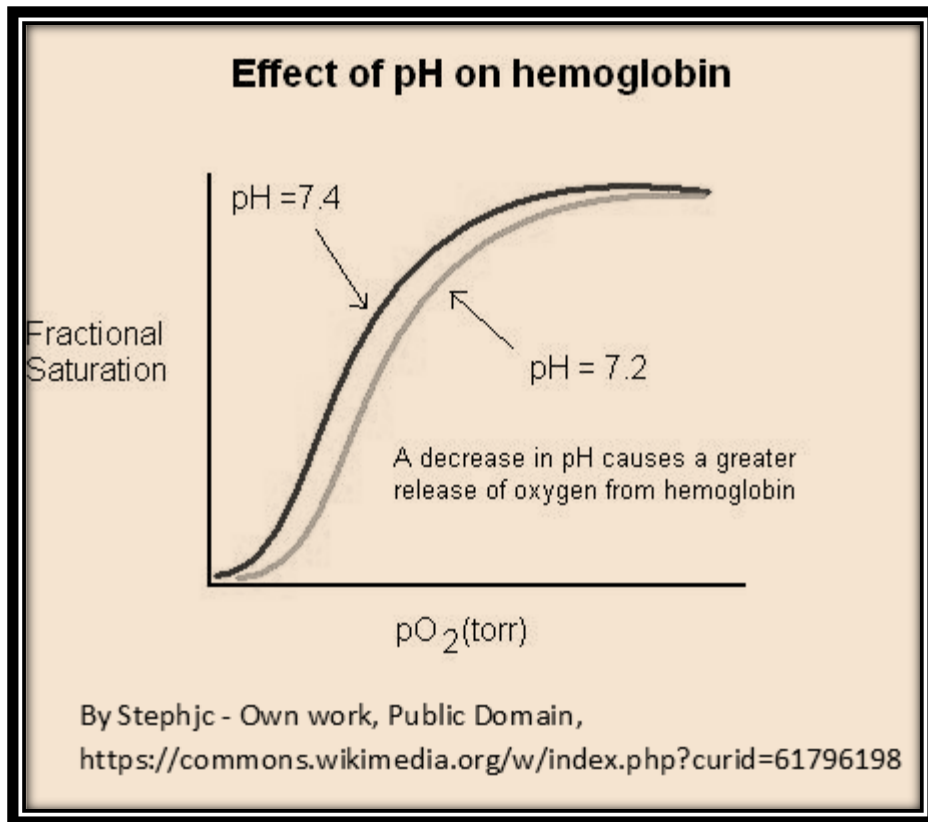
Why? When four O_2 molecules are bound, and of the subunits release O_2 , the other subunits unload O_2 more readily.

Let's talk about the release of O_2 ...

Myoglobin shows no change in O_2 binding over a wide pH range, nor does CO_2 have much of an effect. The story is different for Hb. Consider muscle that is rapidly contracting. CO_2 and H^+ promotes the release of O_2 . Another way to say it is that Hb has decreased its affinity for O_2 . I simply tell my students, Hb dumps its O_2 off. This is called the **Bohr effect**.

Hb's oxygen binding decreases as the amount of CO_2 and H^+ increase. This is the bottom line, here. Let us see this on what is called an oxygen dissociation curve:

Chapter 6 - Myoglobin and Hemoglobin



★ Low pH has “shifted the curve to the right”. It dumped off O_2 !!

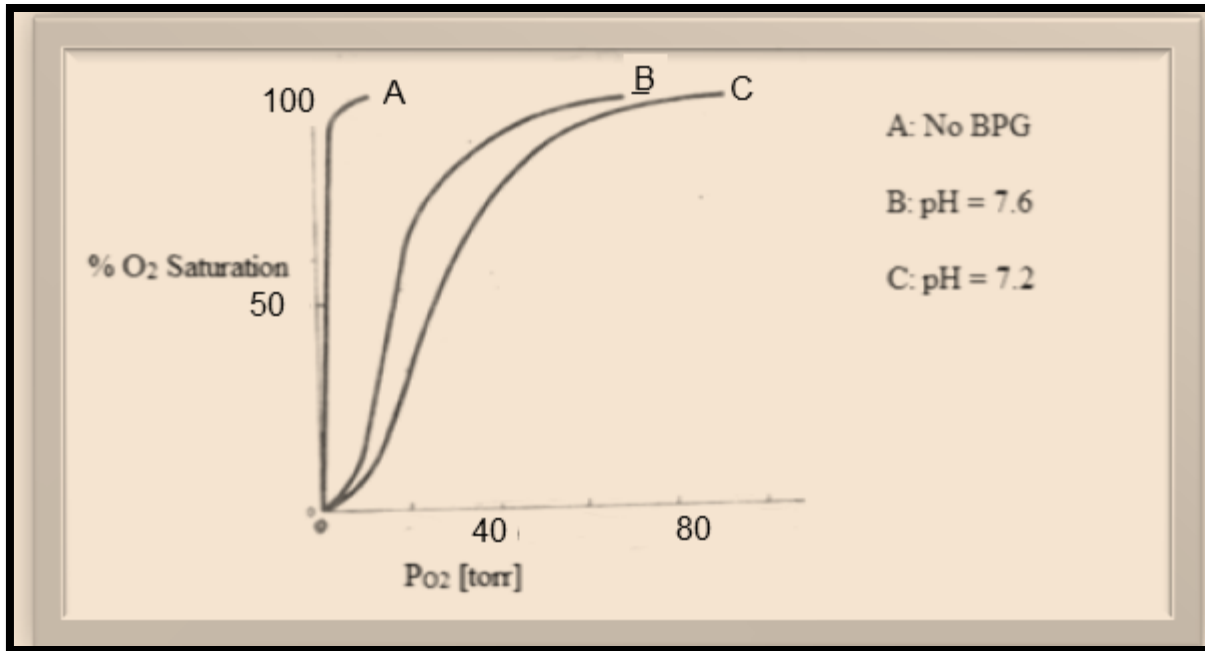
Remember the picture of BPG (sometimes called 2,3-DPG) I showed you at the beginning of this lecture?

This BPG drastically effects the binding capacity of Hb by a factor of 26!!! (This BPG molecule is synthesized from an intermediate in the glycolysis pathway). BPG binds to the deoxy Hb form. The BPG binds the positively charged groups on the β -chain of the deoxy form.

Bottom Line: O_2 dumps off more easily when BPG is around! Again, our Hb curve will shift to the right!

If you ever see this expression “**shift to the right**” and the **DAT loves it**... it simply means that Hb is releasing or dumping off O_2 to the tissues in need!

Chapter 6 - Myoglobin and Hemoglobin

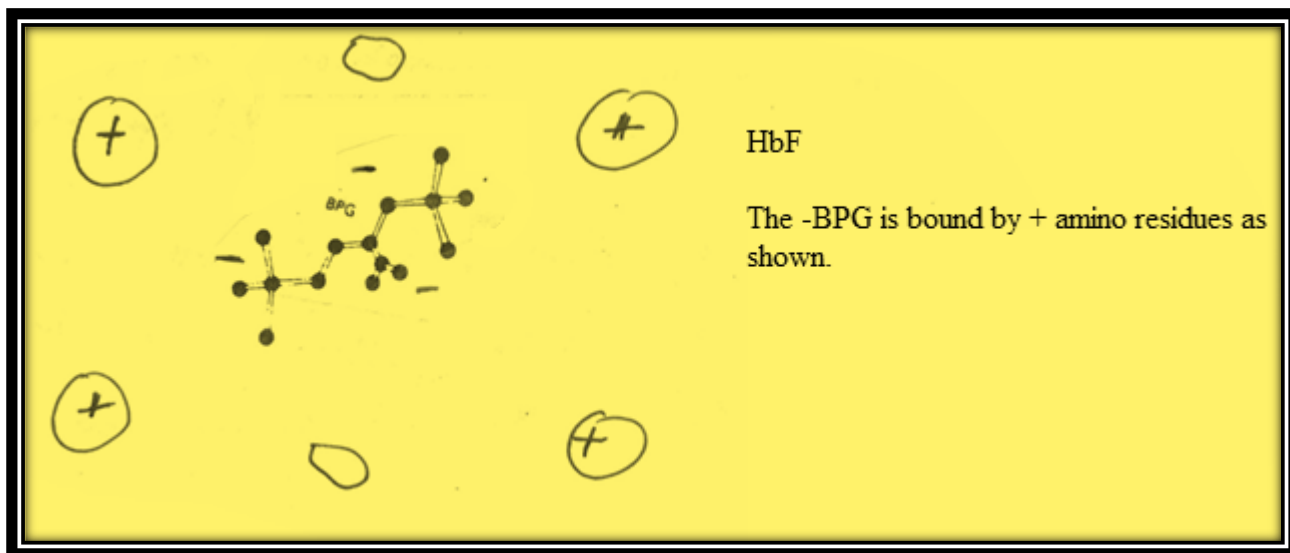


Fetal Hb

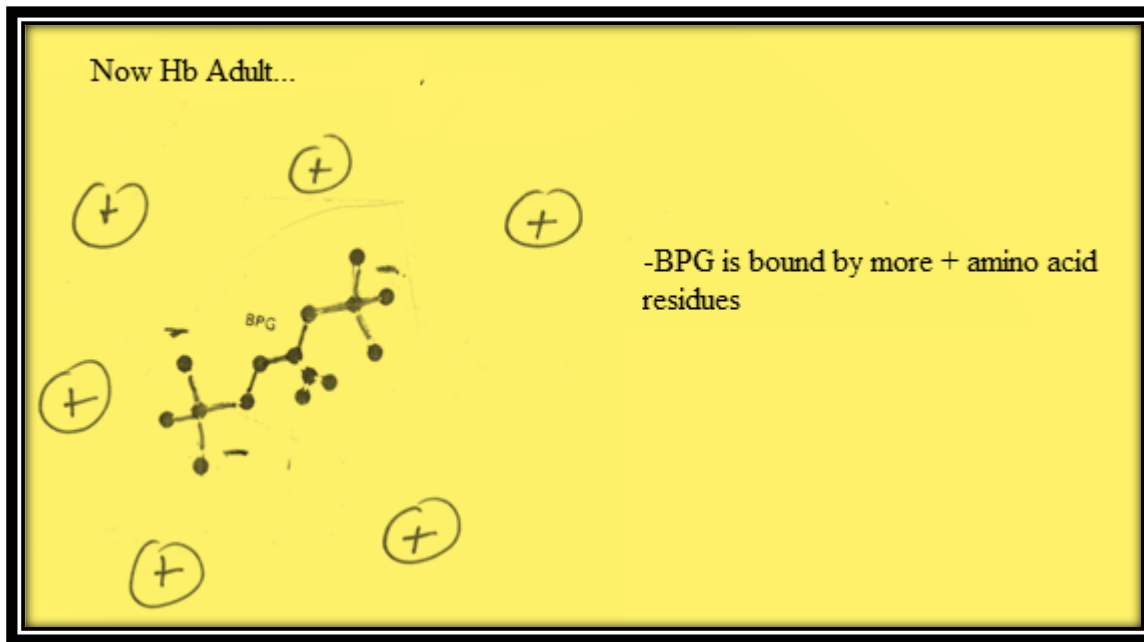
Note: Let us consider fetal Hb. The fetus gets O₂ from the mom's bloodstream by means of the placenta. Fetal Hb has a higher O₂ affinity than does adult Hb. Two reasons:

- 1) Adult has 2 alpha chains, and 2 beta chains
Fetal Hb has 2 alpha chains, and 2 gamma chains
- 2) Fetal Hb binds BPG less strongly than does adult Hb.

Let us see why:



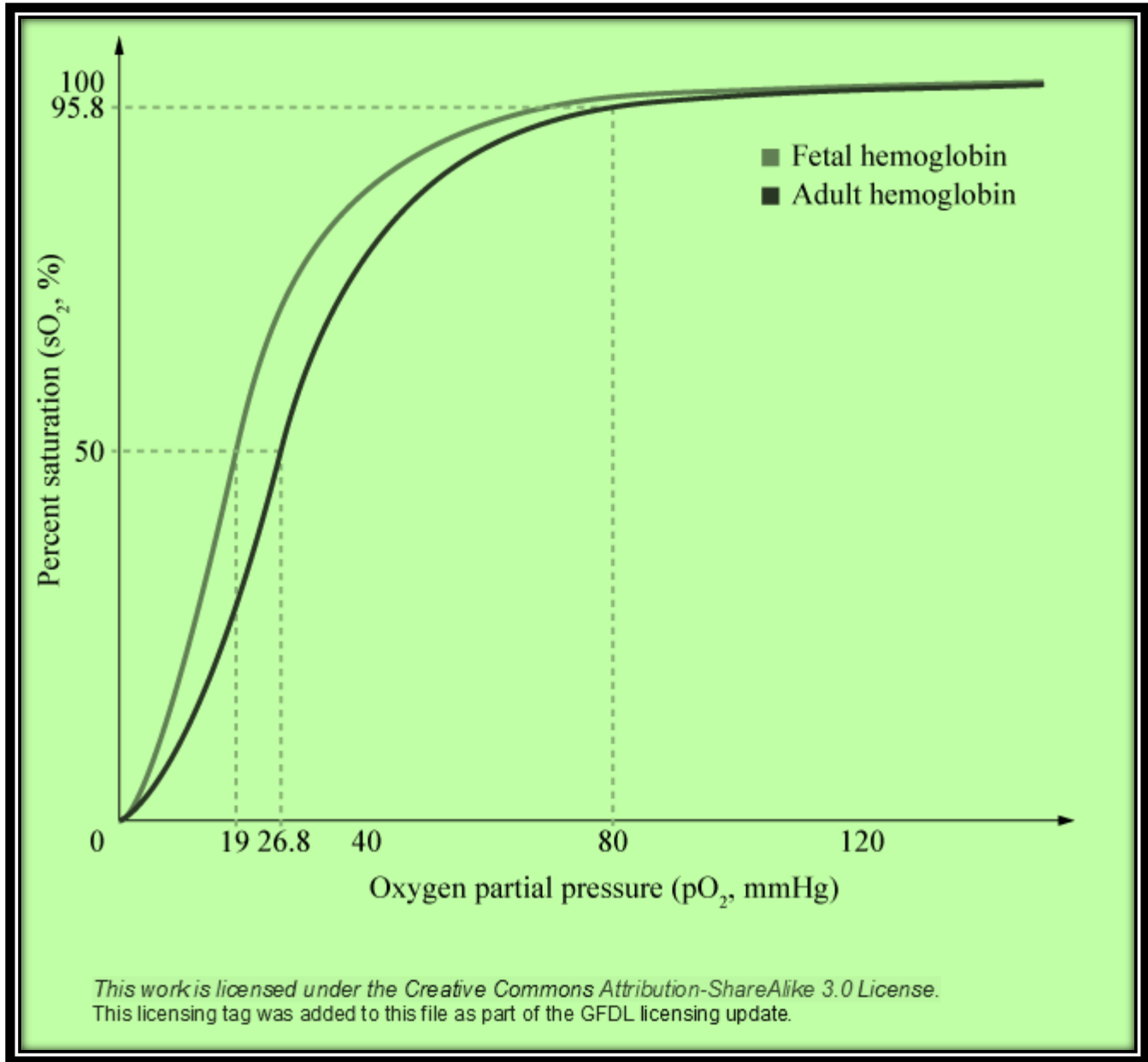
Chapter 6 - Myoglobin and Hemoglobin



Bottom Line: HbF does not hold BPG as tightly. HbAdult holds BPG tighter. This stabilizes the deoxy form which means the “preferred” conformation will be to have O₂ dumped off!!

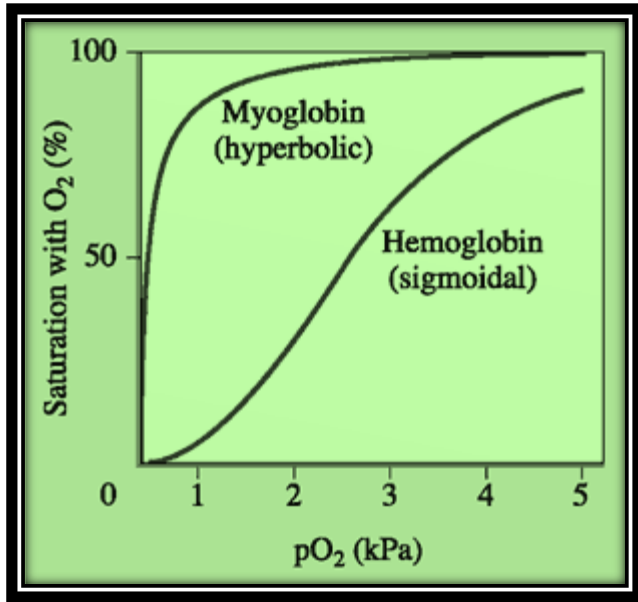
Thus, the hemoglobin curve for fetal Hb is shifted to the left since it will keep its O₂ and use it for its own critical development.

Chapter 6 - Myoglobin and Hemoglobin



Let us compare the Mb vs. Hb oxygen dissociation curve:

Chapter 6 - Myoglobin and Hemoglobin



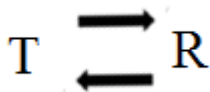
★ These curves tell us that Mb holds on to O₂ tighter and with a higher affinity

For example, look at 20 torr. Mb has a 90% O₂ saturation, whereas Hb about 35%!!

2 forms for Hb:

- a) T form... low O₂ affinity form “deoxyhemoglobin”
- b) R form... high O₂ affinity form “oxyhemoglobin”

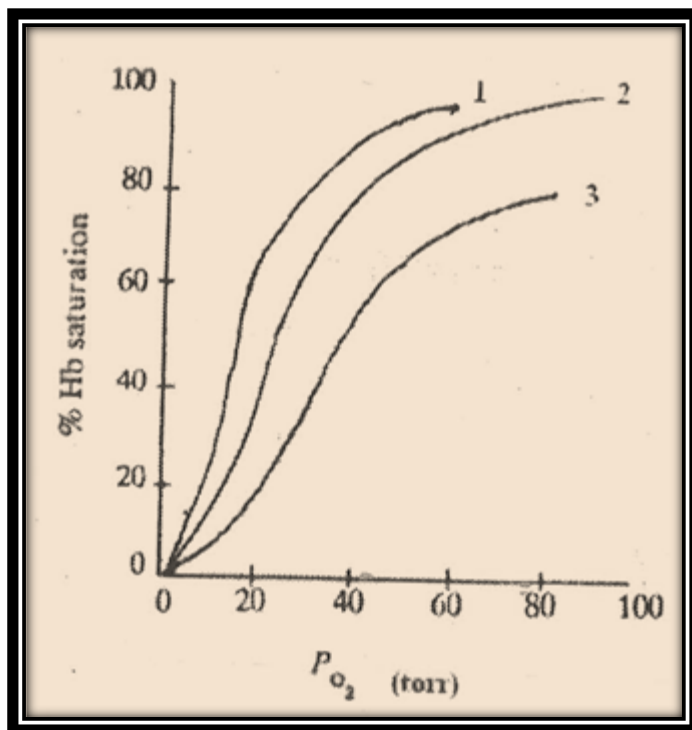
Represents a change in quaternary structure!



At high altitudes, the amount of BPG increases substantially. Thus, the Hb curve shifts to the right because O₂ will be dumped off Hb and released to the tissues. This compensates for the lowered oxygen concentration. Have you ever tried running at a very high altitude? Not so easy!

The higher the metabolic rate of an organism, the greater will be its O₂ demand. This means the curve will be shifted to the right!

Chapter 6 - Myoglobin and Hemoglobin



Organism #3 would have the highest O₂ demand since the curve is furthest to the right:

The Haldane Effect

This refers to a property of the Hb molecule. The deoxyform of hemoglobin increases its ability to carry CO₂. In other words, the removal of O₂ from Hb will increase its affinity for CO₂.

Hb-CO₂ is the major contributor to this effect. Hb-CO₂ is carbamino hemoglobin, a strange name indeed. The CO₂ binds to the amino groups of lysine and arginine residues in hemoglobin.

What shifts the Hb curve to the right?

- a) Increase in temperature
- b) Increase in BPG
- c) Increase in CO₂
- d) Increase in H⁺ or a decrease in pH
- e) Increase in acidity

The left would be the opposite, plus fetal Hb, of course!

Alkalosis is a decrease in acidity and would surely shift it to the left too.

Bottom Line:

Shift to the right: O₂ dumps off Hb

Shift to the left: O₂ wants to stay

Chapter 6 - Myoglobin and Hemoglobin

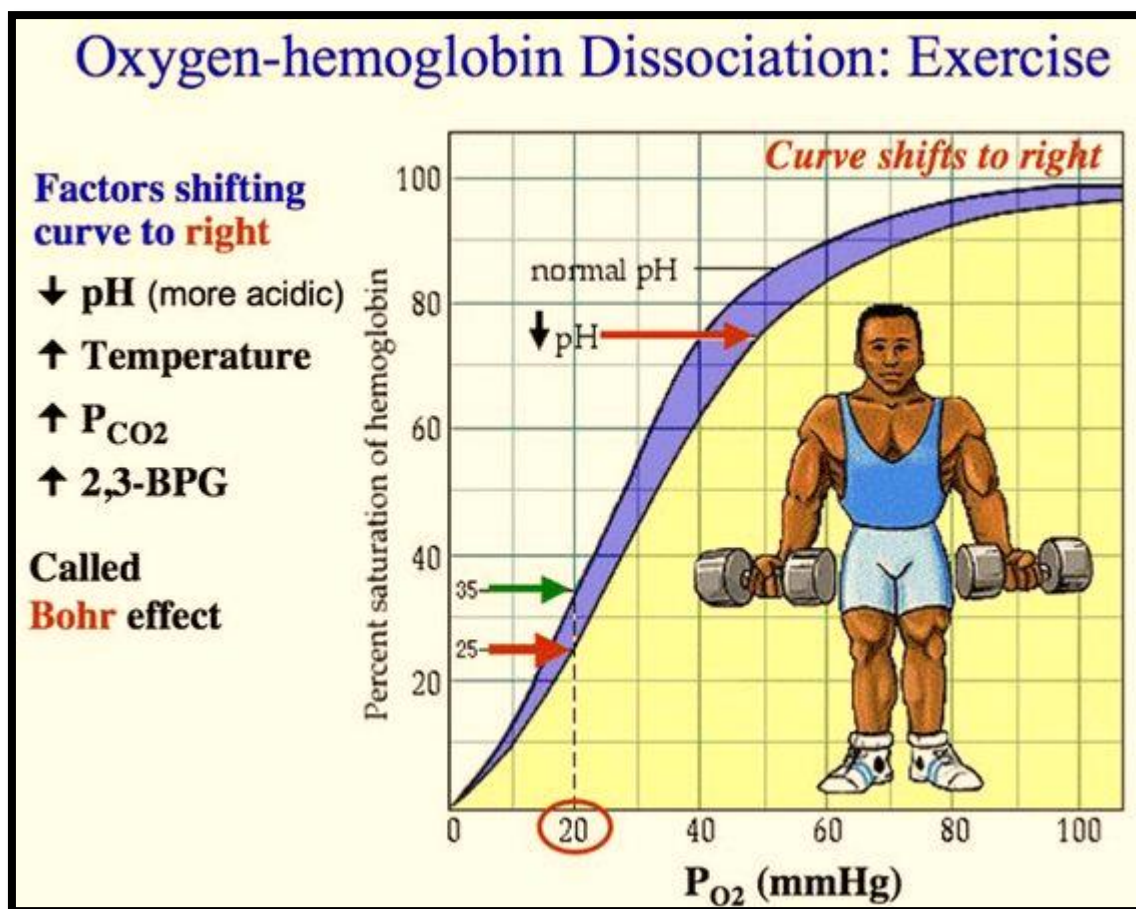
Let's examine CO (carbon monoxide).

Hb binds to CO 240x more readily than with O₂!! There is a lower potential for Hb to bind O₂ thus the curve will be shifted to the left. ★ 2,3-BPG levels are increased.

In **Sickle Cell Anemia** a glutamic acid is converted to a valine

The mutation was on the hemoglobin **β-chain** (A favorite DAT question!)

In electrophoresis, the anode is + and the cathode is -.



In Conclusion

Mb facilitates O₂ transport in muscles and is our O₂ reserve tank for O₂. It is a monomer

Hb is an O₂ carrier in our blood. It is a tetramer.

Chapter 7 -Vitamins

Vitamins



13 have been discovered!

Are organic molecules that have many functions and are needed in our diet in small amounts.

Can function as **coenzymes** or **precursors** for coenzymes.

Fat Soluble Vitamins: A, D, E, and K

No need for any details, but you should know:

Vitamin A: needed for vision, cell membrane health, skin

Vitamin D: promotes growth of healthy bones and teeth

Vitamin K: blood clotting

Vitamin E: Antioxidant helps protect cell membranes, stored in liver and fatty tissues.

Chapter 7 -Vitamins

Excess levels of these vitamins are not good. Toxic levels can accumulate in fatty tissues in the body.

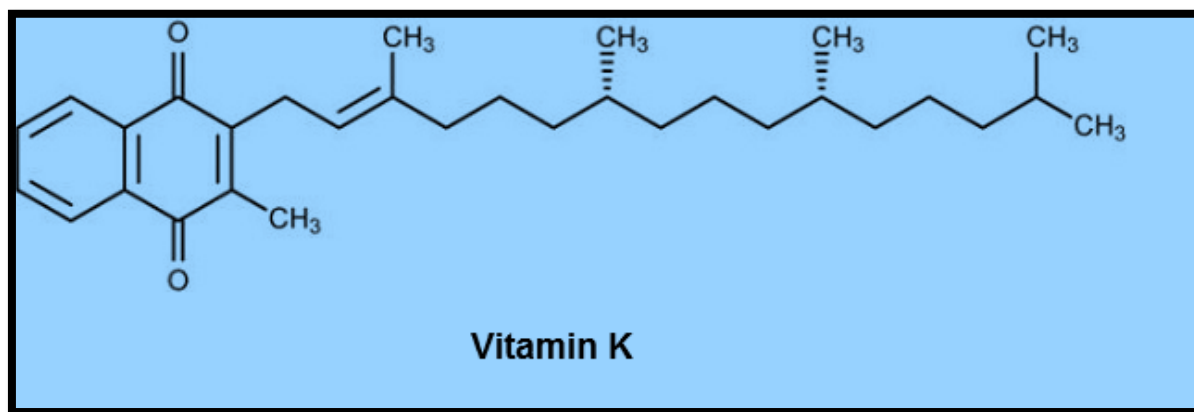
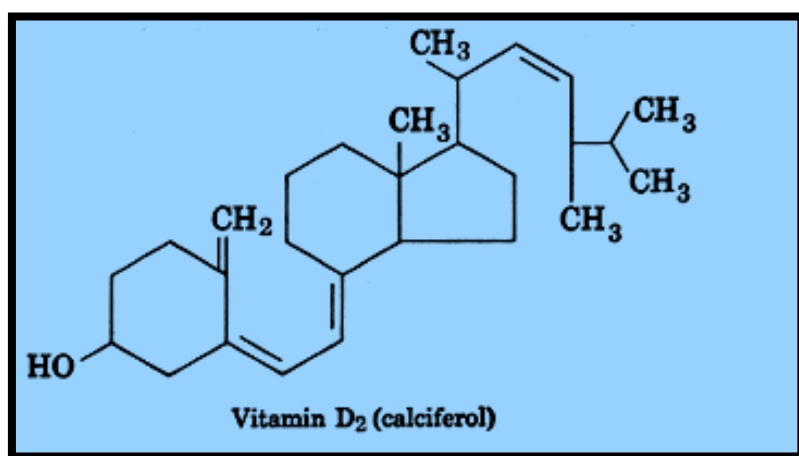
★ Vitamins contain no calories.

The **water- soluble** vitamins are Vitamin C, and a series known as the Vitamin B complex.

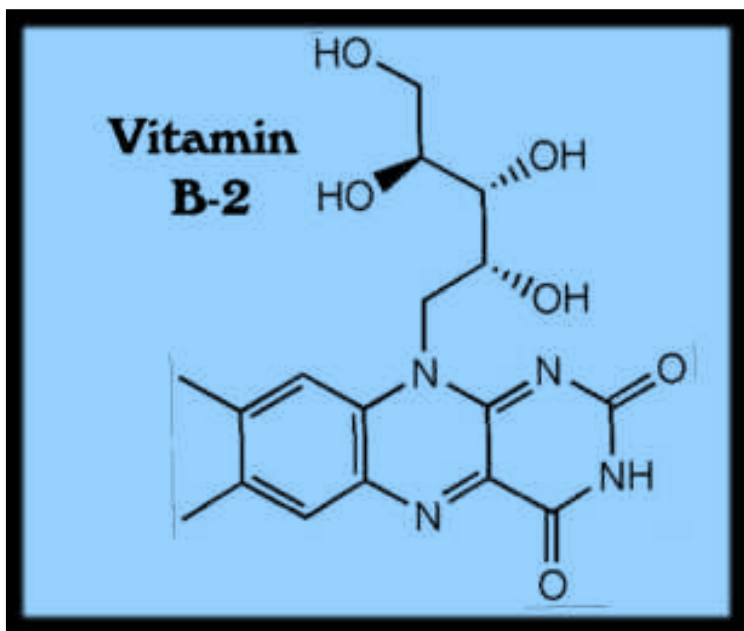
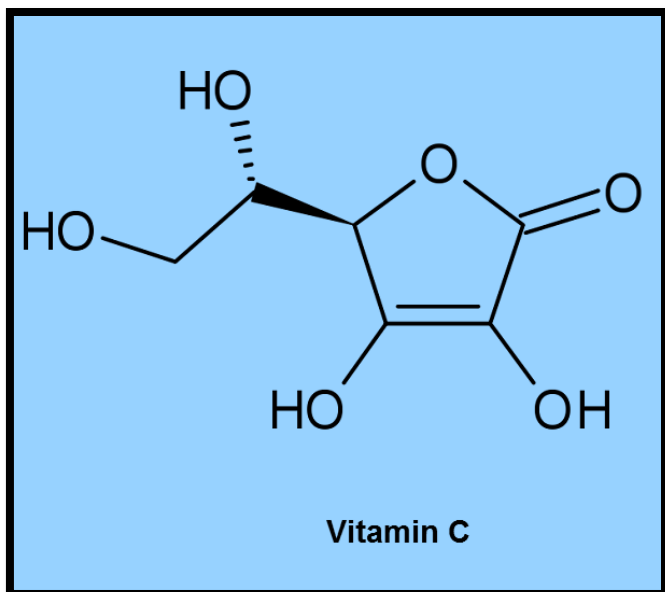
Most water- soluble vitamins are components of coenzymes. For example, Riboflavin (B₂) is a precursor of the electron carrier FAD. Niacin (B₃) is involved with NAD.

Vitamin C is needed for proper collagen formation. Vitamin C is a reducing agent in the hydroxylation reactions as seen when proline becomes **hydroxyproline** in collagen.

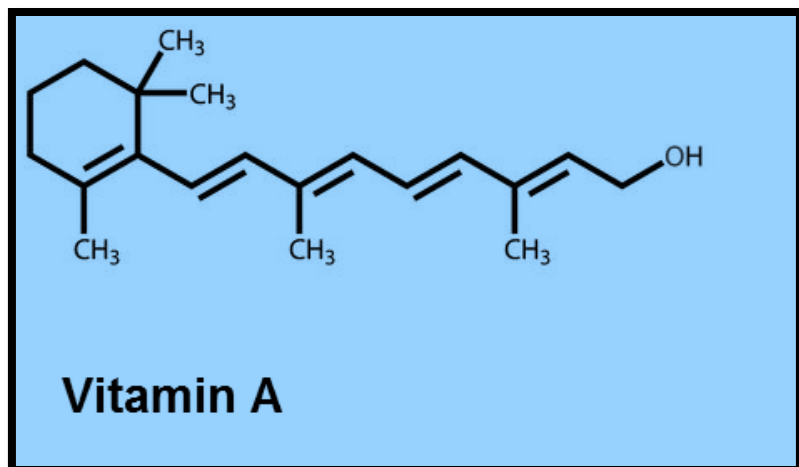
Vitamins differ in molecular structure. Let me give you a quick look at what they look like. No need to memorize, but as future doctors, important to understand.



Chapter 7 -Vitamins



Chapter 7 -Vitamins

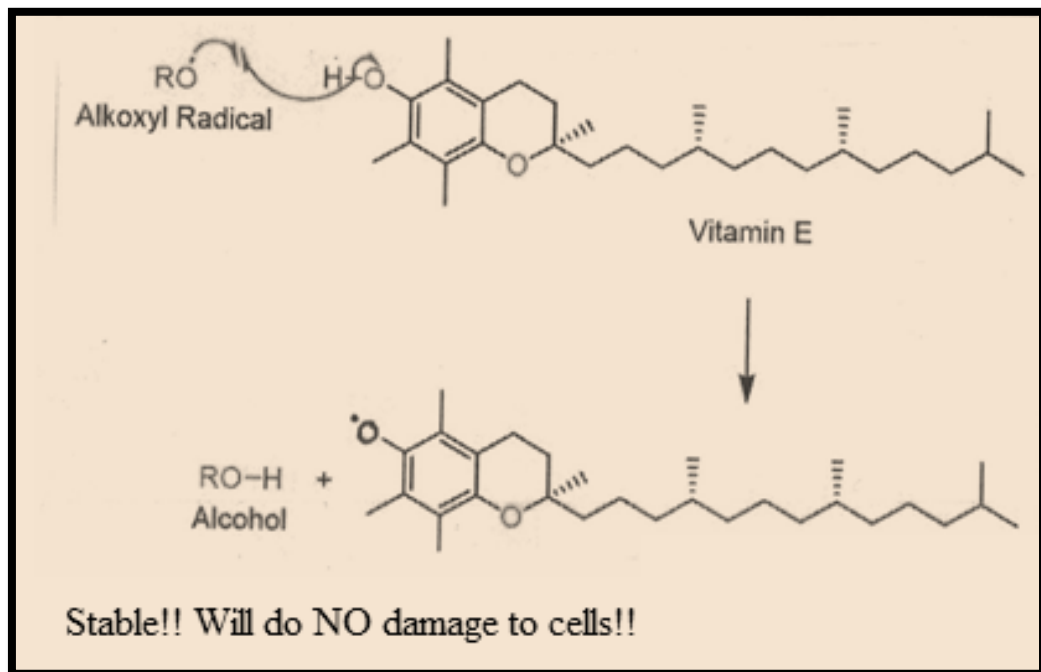


A deficiency of certain vitamins may cause disease. For example, a deficiency of Vitamin C may cause **Scurvy** and a deficiency of Vitamin D may cause **Rickets**, a deficiency of B₃, (Niacin) may cause **Pellagra**.

Chapter 7 -Vitamins

How does Vitamin E work?

Vitamin E is a radical “scavenger”. It will take a “bad” highly reactive radical and destroy it. The resulting Vitamin E radical as I show below is well-stabilized by resonance!



Chapter 7 -Vitamins

Minerals

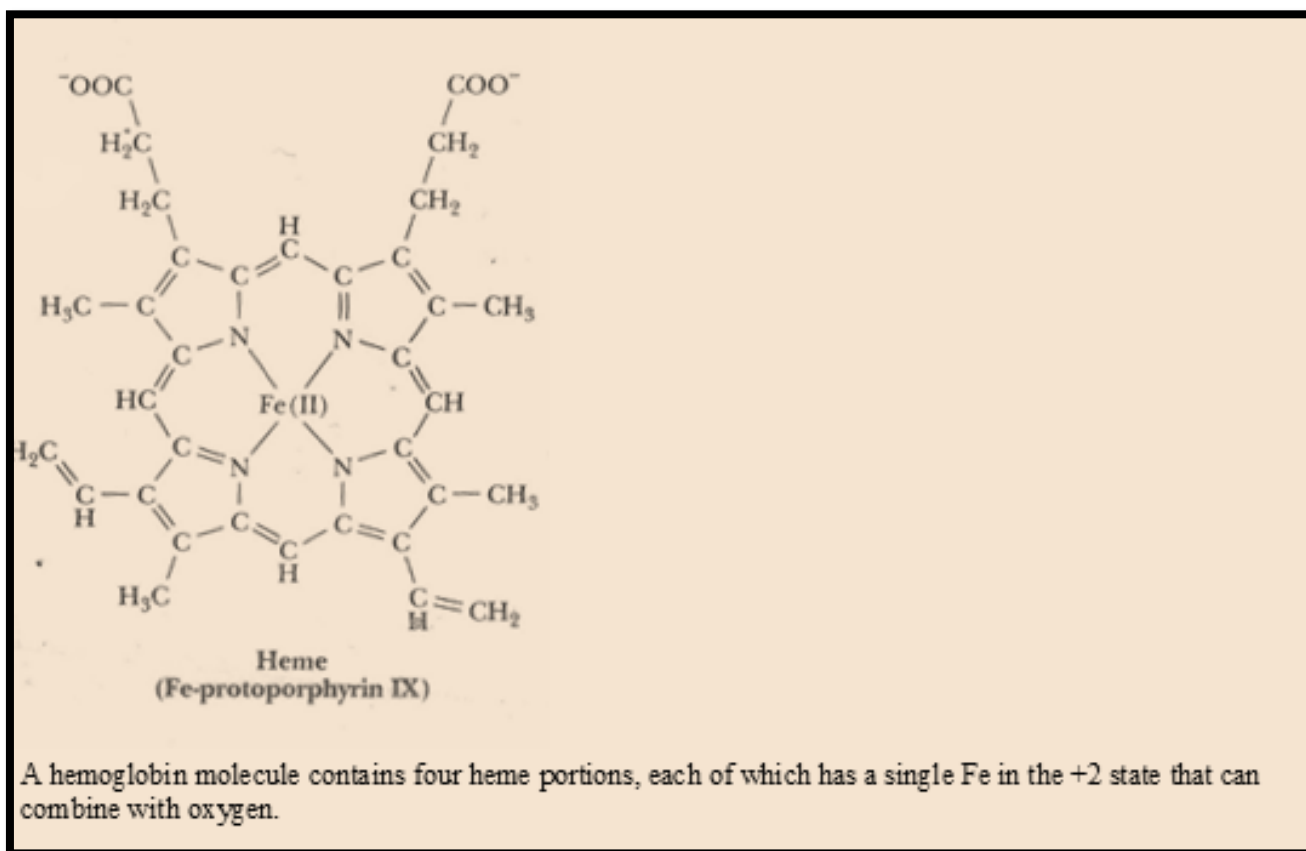
Minerals are the inorganic nutrients such as copper, zinc, molybdenum, chromium, and sodium. They have a wide range of functions. For example, Co is a component of Vitamin B₁₂, Mo is needed for enzymes, Cr is involved with energy production, and Fe is involved with O₂ transport and various enzymes.

Like vitamins, they do not supply ATP (energy).

Minerals are found in all body cells and their concentrations are regulated by homeostatic mechanisms that balance their storage, use, and excretion. Do you know where iodine is most highly concentrated?

The thyroid needs iodine to make its hormones T₃ and T₄.

A healthy diet must supply sufficient calories, essential fats and amino acids in addition to vitamins and minerals to ensure optimal health and growth.



Chapter 8 - Mitosis and the Cell Cycle

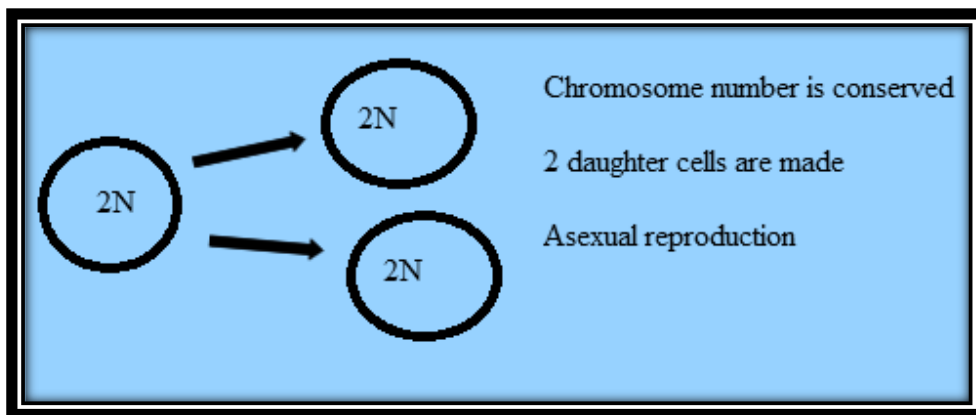
Mitosis and the Cell Cycle

A cell, in order to survive, must have some type of mechanism to reproduce. One such mechanism seen in cells is called **mitosis**.

Mitosis is divided into 5 stages:

- a) Prophase
- b) Prometaphase
- c) Metaphase
- d) Anaphase
- e) Telophase

In mitosis:



Mitosis is actually a small part of the cell cycle. 90% of the cycle is **interphase**. During this phase, we see **growth** and **chromosomes are copied** in order to prepare for cell division.

M-phase:

Includes mitosis and cytokinesis

Usually the shortest of the cell cycle

All five stages are here (prophase, prometaphase, metaphase, etc.)

Interphase:

G₁ “first gap phase”: cell begins to grow

S phase: duplication of chromosomes

G₂ “second gap phase”: cell prepares to divide

★ During all three phases, cell growth is seen, we make organelles and proteins.

Chapter 8 - Mitosis and the Cell Cycle

Good health depends on the efficiency and successful completion of these cycles. Any error in DNA duplication could spell doom and gloom for the organism.

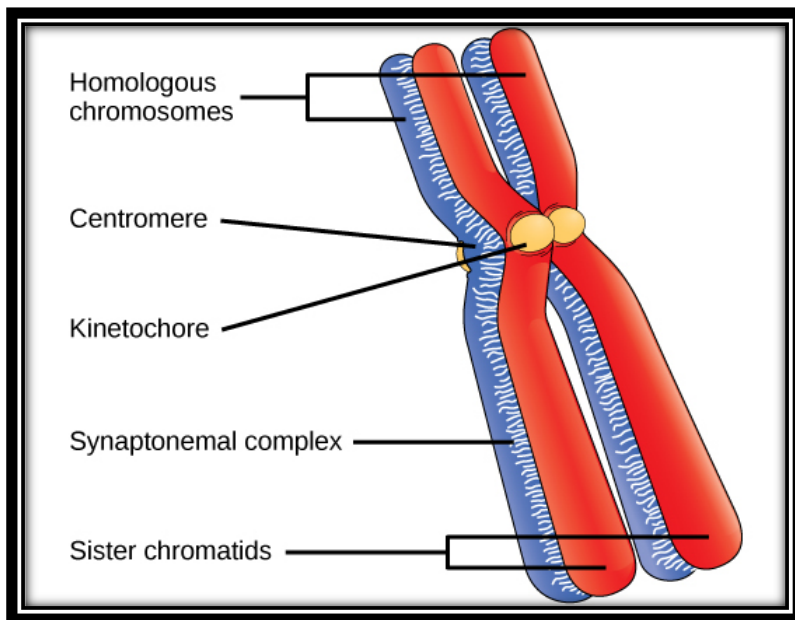
Chromosomes do not move on their own, but are moved by a **spindle apparatus** composed of organized arrays of **microtubules**. In animal cells, the assembly of the spindle microtubules begin at a structure called a **centrosome**. (Recall that flagella and cilia were made from microtubules in a 9+2 arrangement).

The centrosome consists of **two centrioles** (only in animal cells) perpendicular to each other.

Just before mitosis, these two centrosomes move apart until they are opposite sides of the nucleus.

As mitosis proceeds, microtubules grow out from each centrosome. We will call these microtubule clusters the spindle fibers.

Plant cells do not have centrioles, but has a mitotic spindle.



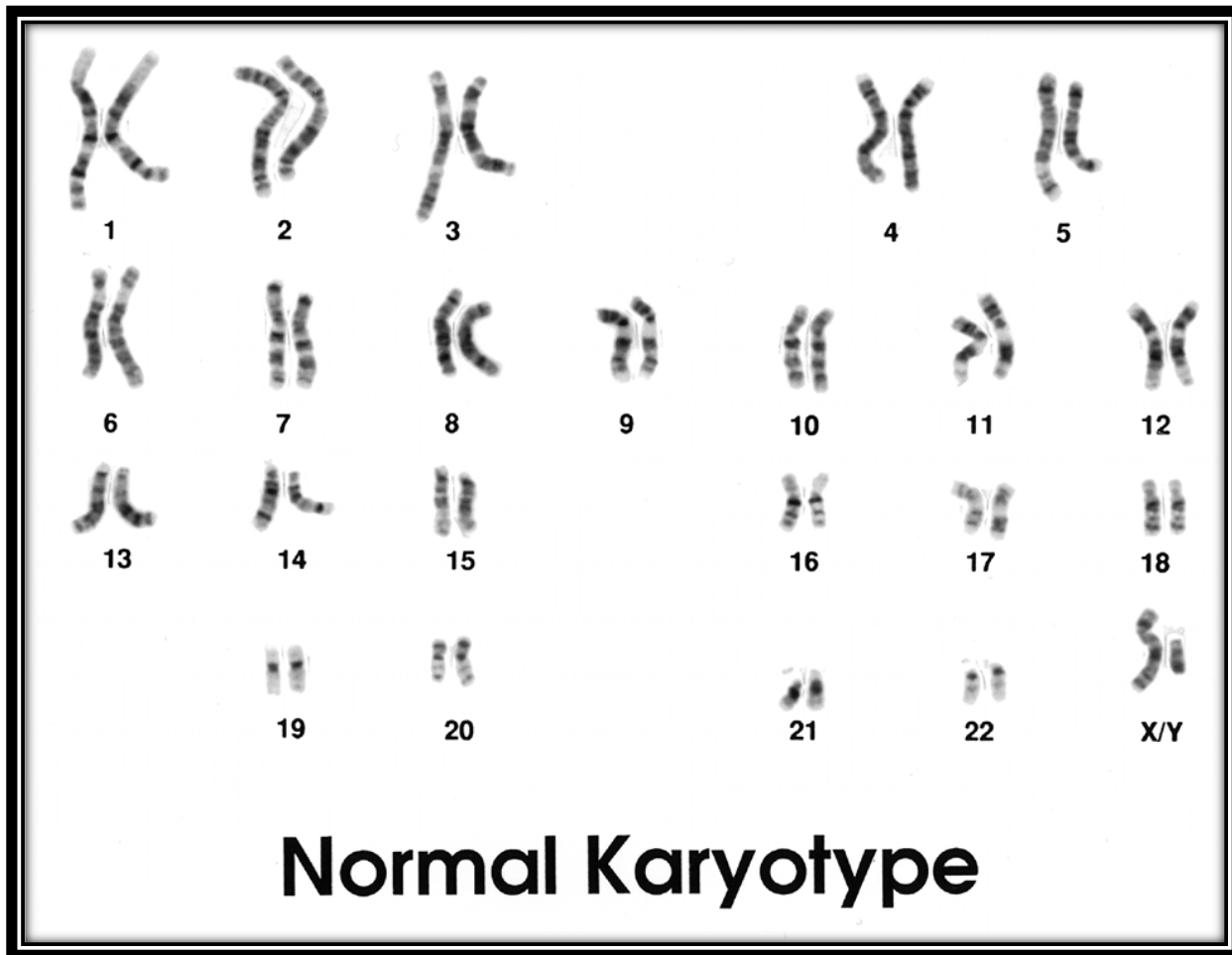
Recall:

Male Human: 44 chromosomes + X + Y
non-sex sex
(autosomes) chromosomes

Chapter 8 - Mitosis and the Cell Cycle

Female Human: 44 chromosomes + X + X
(autosomes) sex chromosomes

Chromosomes are viewed in the following **karyotype**:



Let us now look at these stages of mitosis:

Stage One: Prophase

Nucleoli disappear

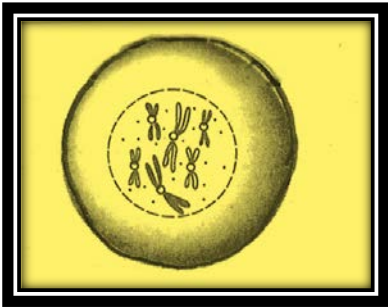
Chromosomes condense

Centrioles move to opposite poles

Chapter 8 - Mitosis and the Cell Cycle

Mitotic spindle begins its formation

Chromatin fibers become tightly coiled; chromosomes are observable under a light microscope.



Stage Two: Prometaphase

Chromosomes become more condensed

Nuclear envelope fragments



Nuclear envelope surrounds the nucleus... has an inner and outer membrane.

The nucleus protects the DNA and will help to contain repair enzymes and regulatory proteins.

Some of the microtubules attach to the **kinetochores**. A kinetochore is a protein structure attached to the centromere that links the sister chromatids to the mitotic spindle. **It is vital you understand this... see a picture!!** Kinetochore belongs to the chromosome!! Barron's has nice pictures. **One was also posted in our Facebook DAT Destroyer study group.**

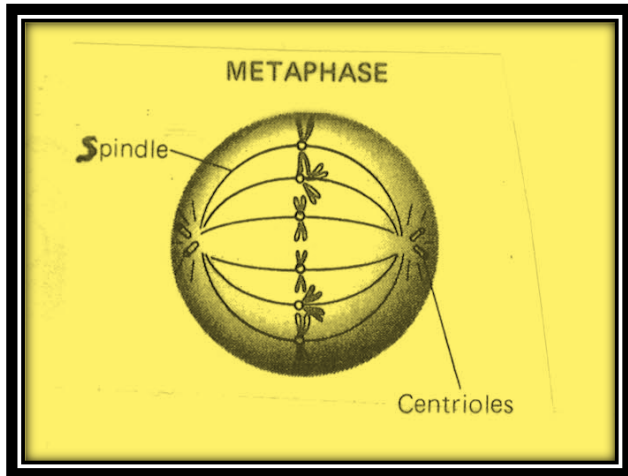
Chapter 8 - Mitosis and the Cell Cycle

Stage Three: Metaphase:

Centrosomes are officially at opposite ends.

Sister chromatids of each chromosome are attached to the spindle.

Chromosomes are now lined up at the spindle equator.

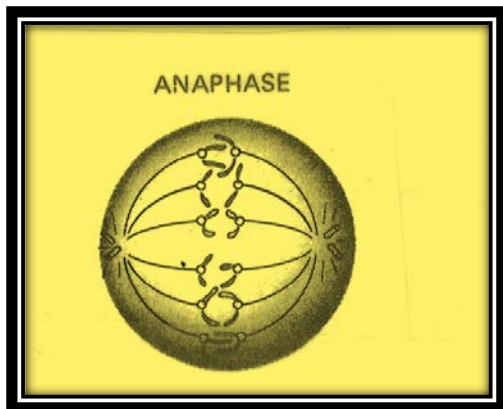


Stage Four: Anaphase

Shortest stage of mitosis

Cohesion proteins are cleaved, thus allowing the sister chromosomes to separate from each other and move to opposite poles.

★ At the end of anaphase, cytokinesis begins



Stage Five: Telophase

2 daughter nuclei form, each with a diploid $2N$ number

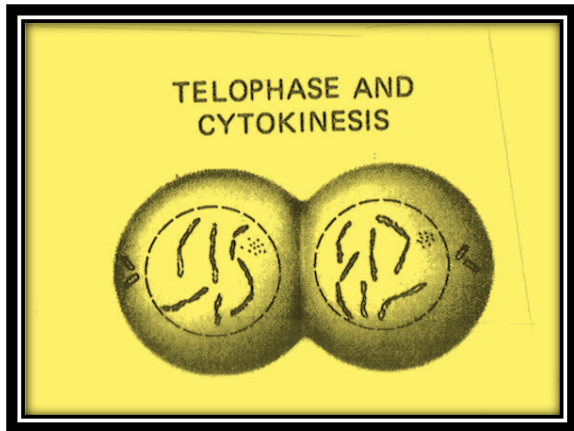
Cytokinesis occurs, but often begins a bit earlier.

Chapter 8 - Mitosis and the Cell Cycle

Chromosomes decondense

New nuclear membranes form

★ In animal cells, cytokinesis involves the formation of a “**cleavage furrow**” as I show in this drawing. Note how the cell “pinches” in two!! This furrow is the first sign of cleavage.



Cytokinesis is different in plants, which have cell walls. There is no cleavage furrow, but we form a **cell plate**. This cell plate will partition off the daughter cells.

Bacteria and Archaea (prokaryotes) reproduced by what is called **binary fission**. We see a parent cell replicating its single chromosome, then dividing it into two genetically identical daughter cells... asexual reproduction!

What is a “**checkpoint**”?

This is a term we use when discussing cell cycles. The cycle is regulated with “stop” and “go” signals, much like a red or green traffic light.

G₁ check point is considered the most important. This checkpoint will respond to **DNA damage**. If the cell gets the “OK” signal from G₁, the cell cycle can continue. Neil Campbell, in his textbook called it the “**restriction point**” - a term well used, indeed.

If the G₁ checkpoint is not passed, the cell switches to the nondividing state called G₀.

Most cells are G₀ in our bodies.

Growth factors might allow the G₀ phase to be reactivated.

Various enzymes and growth factors are involved with these checkpoints.

In a cancer (malignancy), we see an uncontrolled mitosis. Abnormal changes occur within a cell, and control point activity is lost.

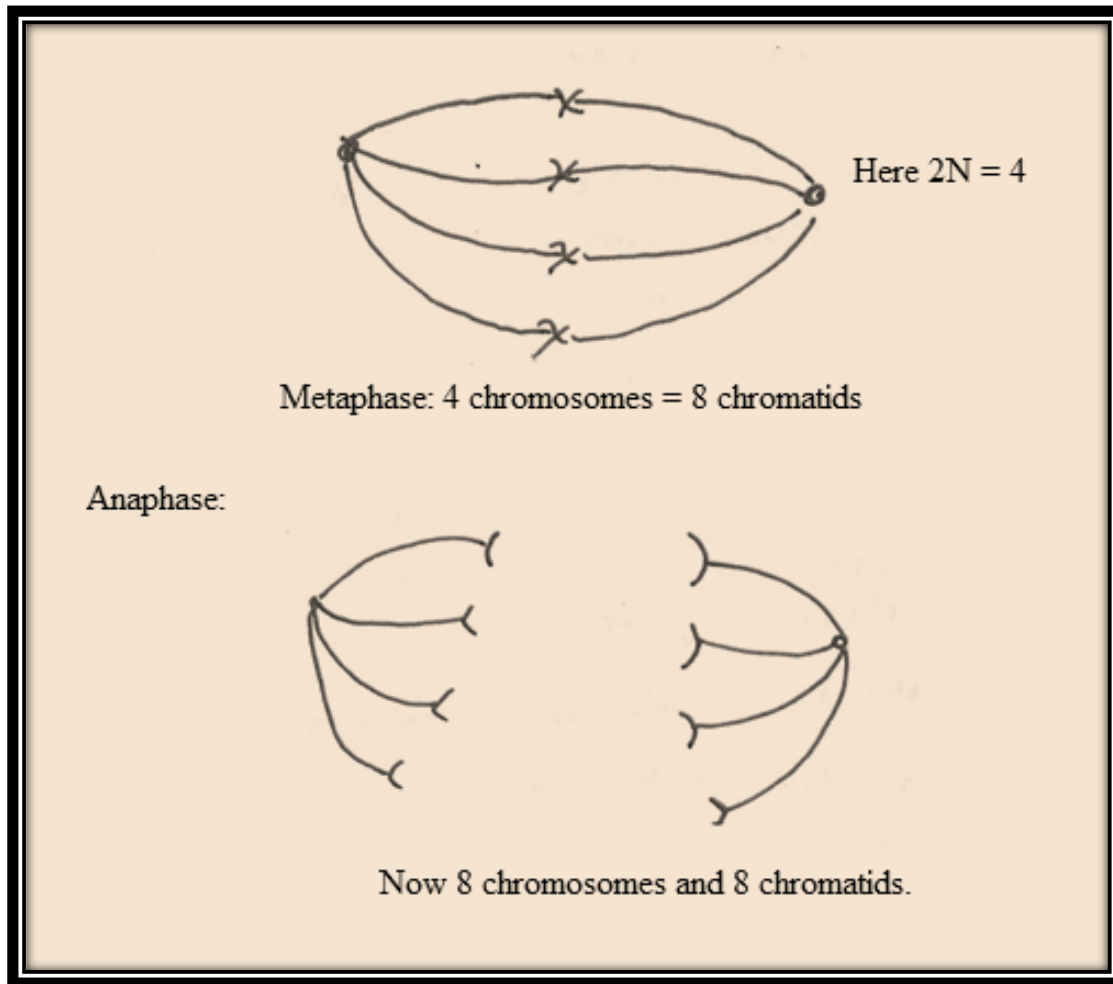
Cancer cells can lose their cell attachment and often spread (metastasize) to distant sites.

For example, a person with breast cancer can eventually get liver cancer.

Chapter 8 - Mitosis and the Cell Cycle

Some chemotherapy drugs disrupt the mitotic spindle which would stop cell division.

★ **Colchicine** is a specific drug that destroys microtubules, thus stopping mitosis.



Favorite DAT-type question!

Definitions to know:

Somatic cells: all body cells except reproductive cells like eggs and sperm (haploid cells "N")

Gametes: eggs or sperm cells

Genome: the genetic info in a cell

Aster: an array of microtubules that extends from each centrosome

Spindle: structure made up of proteins and microtubules. The spindle includes centrosomes, asters, and microtubules

Zygote: fertilized egg cell (2N)

Chapter 8 - Mitosis and the Cell Cycle

Apoptosis: programmed cell death (e.g. eyes of a baby open, webbing of fingers). Neighboring cells, however suffer no damage. White blood cells also die by apoptosis, some white blood cells live for days, others live for years!!

Tumor: clump of overlapping cells-can be malignant or benign

Neoplasm: a new and abnormal growth

How big can we grow?

Cell size is limited by two main factors:

- 1) Nucleus Capacity: must have enough DNA
- 2) Surface area to volume ratio

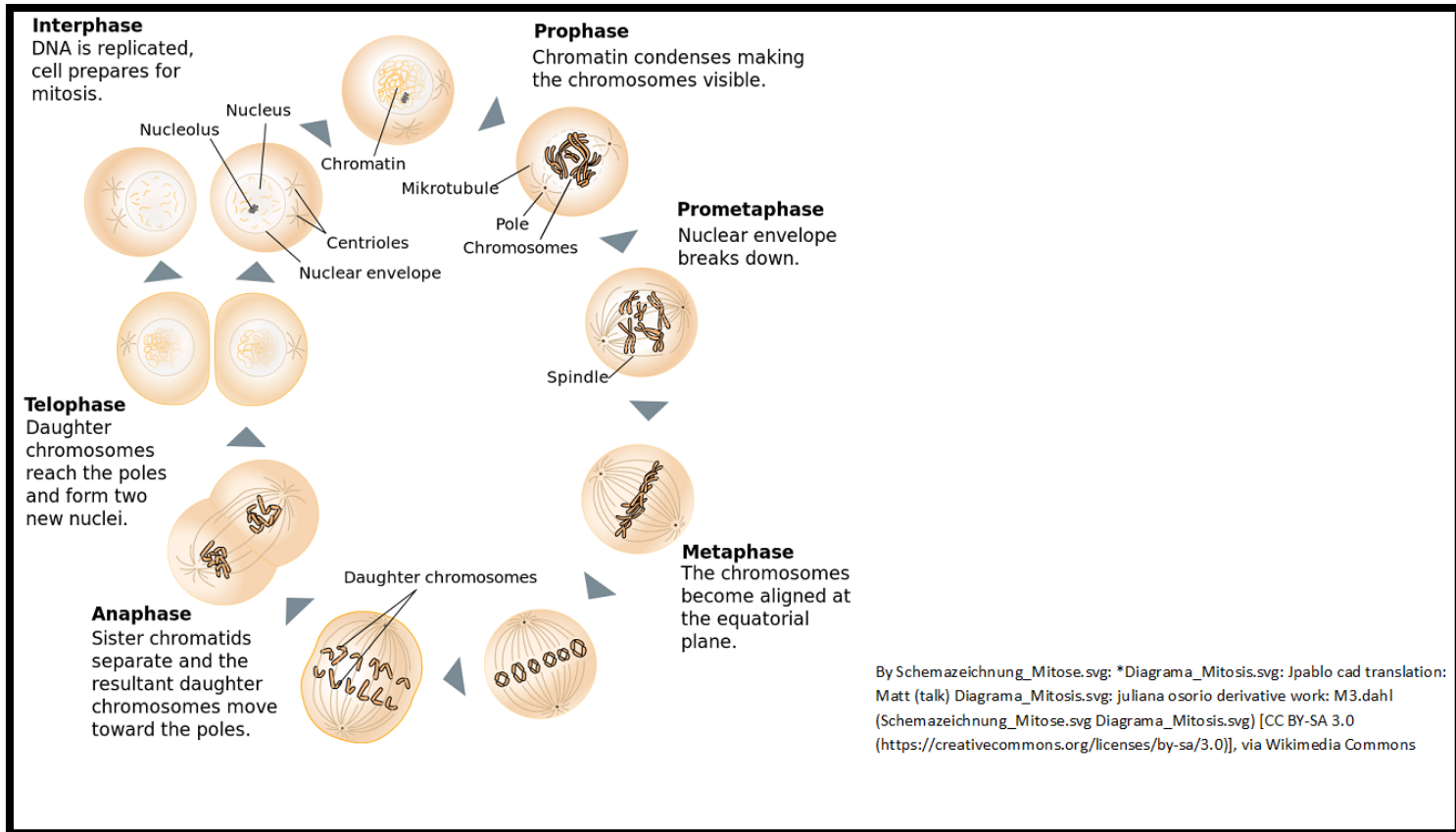
Having a large surface area to volume ratio allows materials and wastes to go into and out of the cell more rapidly and more efficiently.

As a cell grows, its surface area to volume decreases. As a cell increases in size, both area and volume naturally increase, but volume increases at a higher rate. This leads to a lower surface area to volume ratio when a cell increases in size.

When the surface area gets too low, the cell cannot meet its energy and metabolic requirements. Hence, the cell undergoes a cell division.

This should give you a nice review of mitosis. Clearly you see that control of this process is an absolute necessity.

Chapter 8 - Mitosis and the Cell Cycle



Next, we will look at sexual reproduction. We call this **meiosis**.

Chapter 9 - Meiosis

Meiosis

Form of cell division that produces the egg and sperm cells... gametes.

Four daughter cells which are haploid are produced from a single precursor cell.

Chromosome number is reduced in half.

Cell will divide **twice** after chromosome replication, in contrast with just once as seen in mitosis.

Happens only in **germ cells**... the cell lineage destined to yield gametes.

Two Divisions occur:

Meiosis I:

this is a reductive division

Homologous chromosomes separate we will see: Prophase I, Metaphase I, Anaphase I, Telophase I, and cytokinesis

In prophase I:

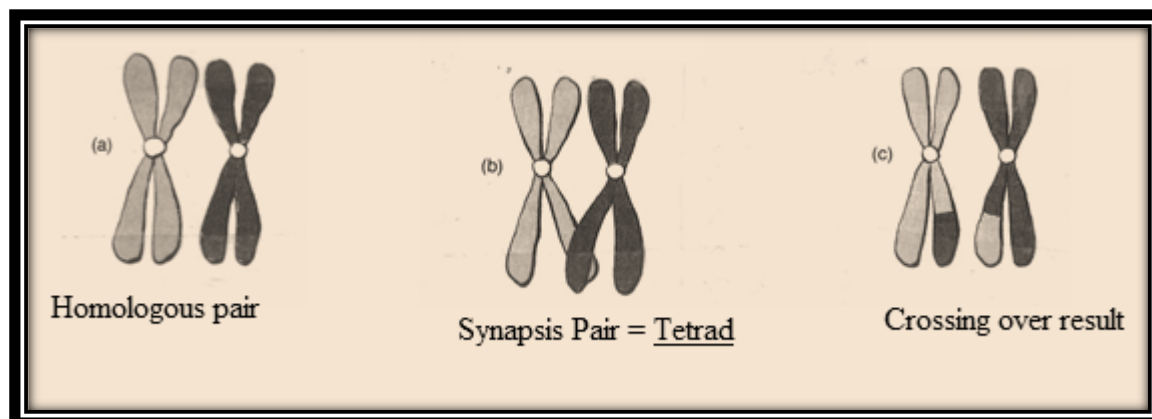
Homologous chromosomes align in such a fashion that their genes match up. This is where **crossing over** occurs. As a result, new combination to alleles (one of 2 or more alternative forms of a gene or given position or locus), replace old ones in a chromosome.

Crossing over allows for **variation** to occur.

Synapsis or pairing of homologous chromosomes also occurs in Prophase I.

Major reshuffling occurs here!

★ Crossing over occurs when all four chromatids are synapsed as shown below:



Chapter 9 - Meiosis

Hundreds or thousands of genes may reside on each chromosome. The chromosome moves as a unit during this process, any loci on the same chromosome are likely to stay together as if they were “linked”.

Let me define **linkage**: the tendency of genes on the **same chromosome** to stay together in the same gamete.

Bottom Line: The greater two genes are in distance, the greater is the possibility of a cross over and recombination between them.

For example:



Crossing over is more likely to disrupt the X-Y linkage more frequently than A-B.

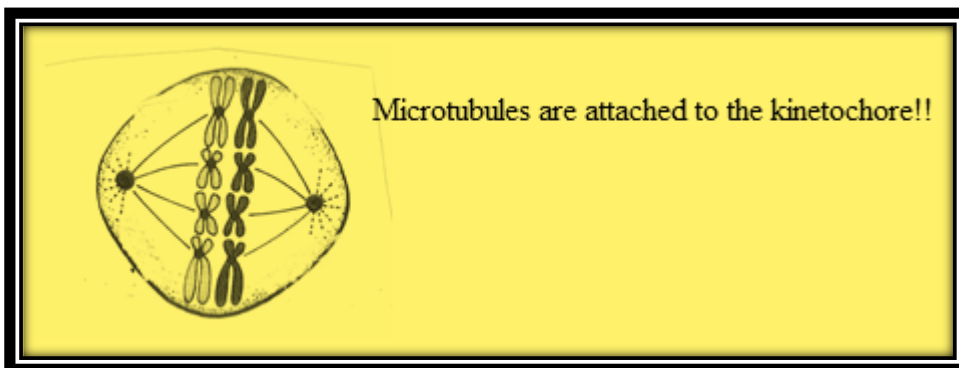
The visible evidence of a crossover is a **chiasmata**. The area that is shaped like an X, it is where homologous non-sister chromatids exchanged their genetic material via crossover.

The **synaptonemal complex** maintains the synapsis process in a fixed state until crossing over occurs. It is a protein that provides a structural framework for crossing over to occur.

The synaptonemal complex is a highly ordered proteinaceous structure that actually aids in stabilization for proper chromosomal alignment during Prophase I.

In Metaphase I:

Synaptic pairs line up as shown below:



In Anaphase I:

Each pair of homologous chromosomes separate as shown below:

Chapter 9 - Meiosis



★ Not sister chromatids but separation homologues! **A huge point to remember!!**

In Telophase I and accompanied cytokinesis:

Two haploid cells form, two chromatids (sister) still make up a chromosome.



Meiosis II:

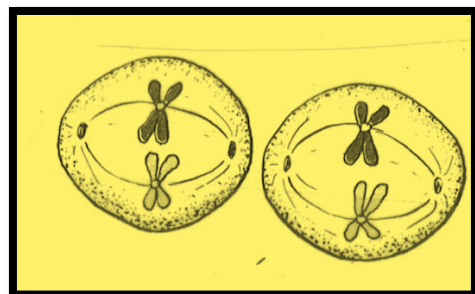
Similar to mitosis

A spindle apparatus forms

The #1 function is to separate the two sister chromatids.

Metaphase II:

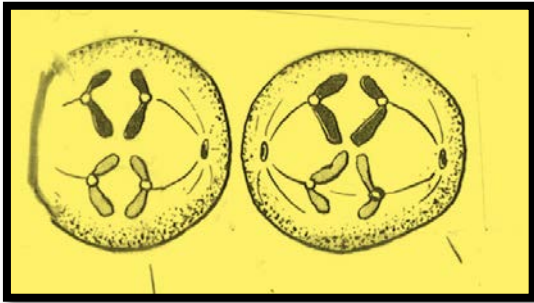
Double stranded chromosomes become attached to the spindle, each chromosome is aligned at spindle equator.



At Anaphase II:

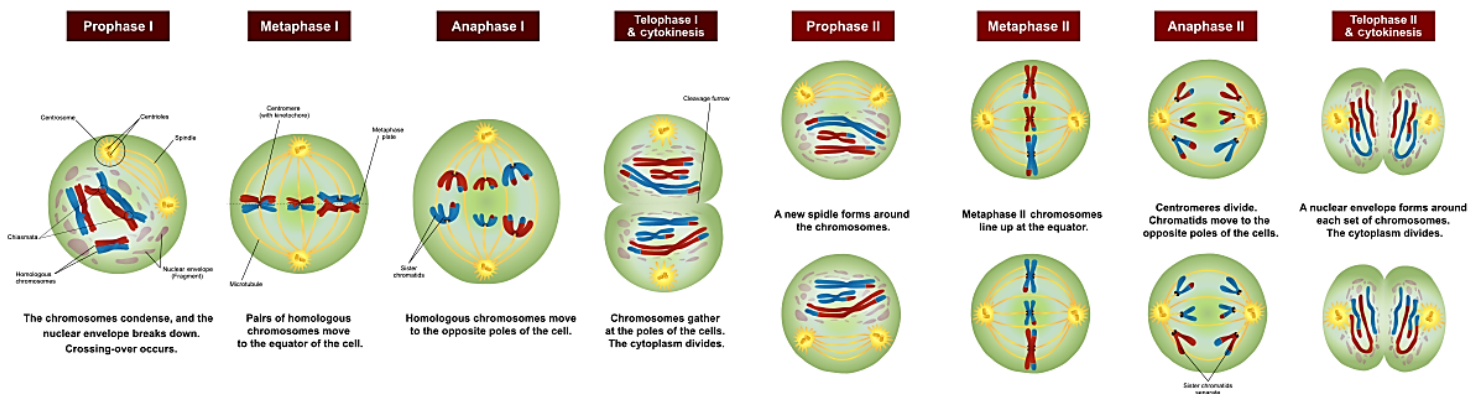
Chapter 9 - Meiosis

Each chromosome splits; sister chromatids are now chromosomes in their own right and migrate to opposite poles as shown:



Finally, Telophase II and cytokinesis:

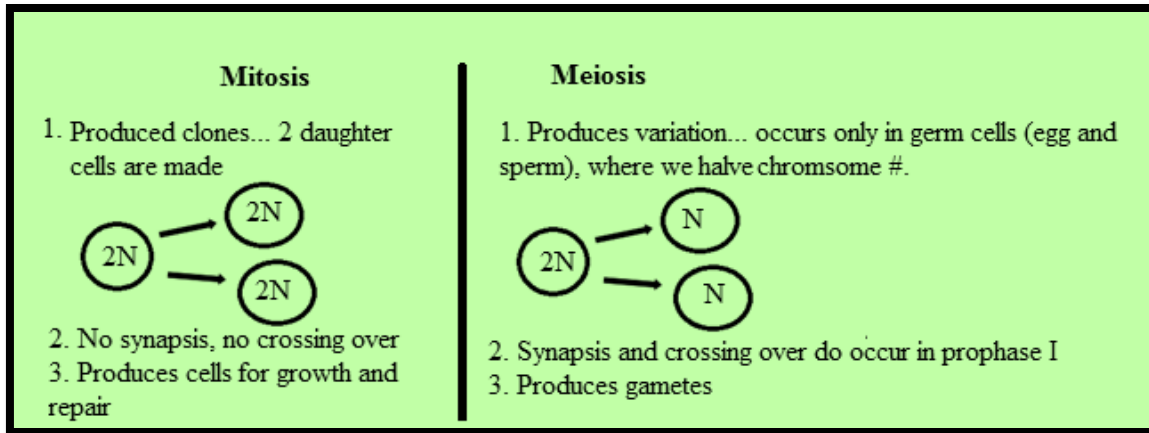
Four daughter nuclei form; after cytokinesis each gamete has a haploid number of chromosomes.



By Ali Zifan [CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/>)], via Wikimedia Commons

Let us now summarize the differences between mitosis and meiosis...

Chapter 9 - Meiosis



Fill in the blanks:

Synaptonemal complex will form during _____.

Answer: Prophase I of meiosis

Chromosomes are photographed when most condensed in _____ for a karyotype.

Answer: Metaphase

Meiosis will give rise to _____, while fertilization gives rise to a _____.

Answer: Gametes, zygote

Fertilization is also called _____.

Answer: syngamy

Complete the table:

Mitotic Phase	Chromosome #	Chromatid #
Prophase		
Metaphase		
Anaphase		
Telophase		

Answer:

Mitotic Phase	Chromosome #	Chromatid #
Prophase	46	92
Metaphase	46	92
Anaphase	92	92
Telophase	92	92

Chapter 9 - Meiosis

Meiosis I	Chromosome #	Chromatid #
Prophase I	46	92
Metaphase I	46	92
Anaphase I	46	92
Telophase I	46	92
End of Meiosis I	23	46

Meiosis II	Chromosome #	Chromatid #
Prophase II	23	46
Metaphase II	23	46
Anaphase II	46	46
Telophase II	46	46
End of meiosis II	23	23

Spermatogenesis

Formation of sperm

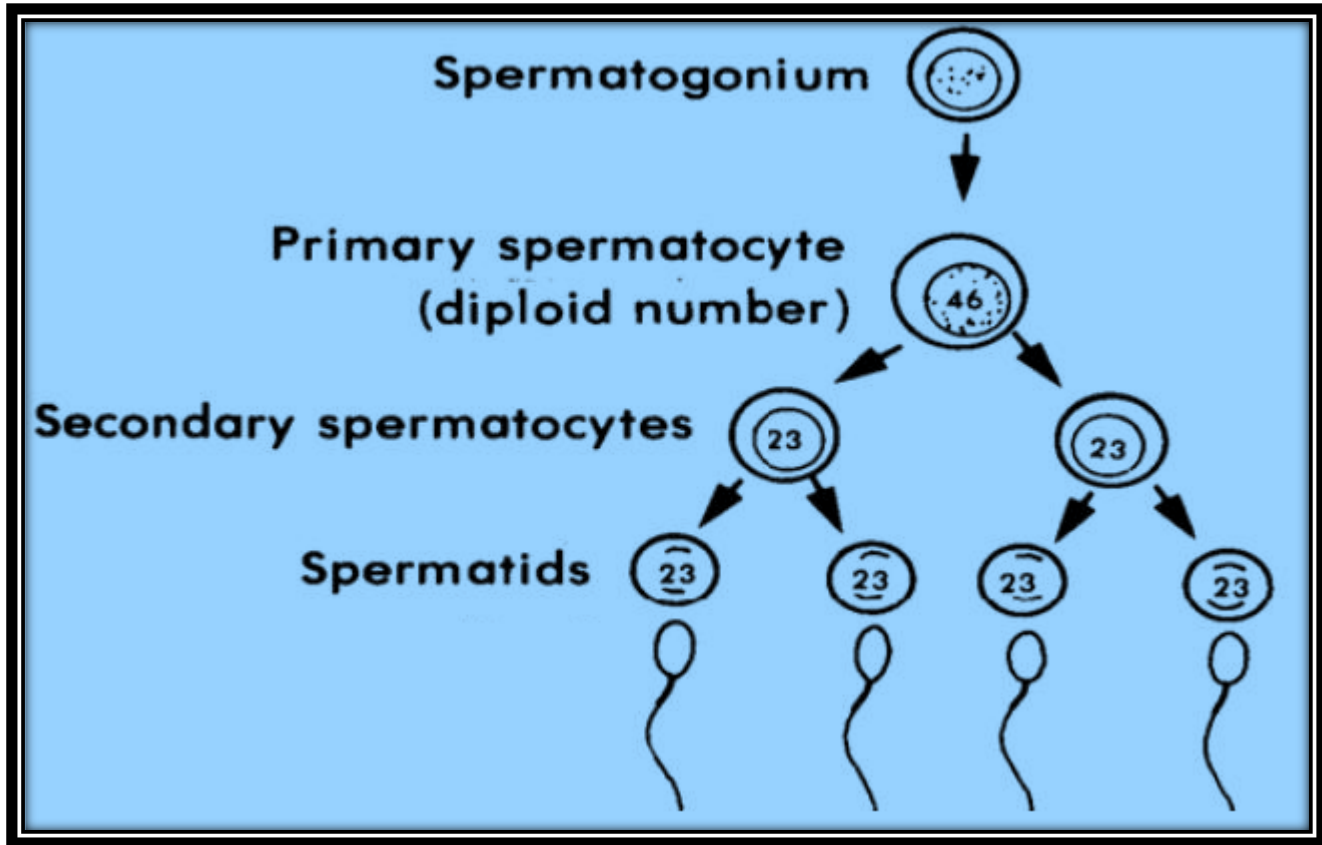
Occurs within the **seminiferous tubules of testis**

Continuously being made

Involves meiosis and differentiation to yield 4 mature spermatozoa.

Involves LH and FSH working together.

Chapter 9 - Meiosis



Make sure you know which cells are 2N and which cells are N!!

In humans, head of sperm = **acrosome**. The acrosome contains **hyaluronidase** enzymes which can break down the zona pellucida (outer membrane of ova), allowing for syngamy (fertilization).

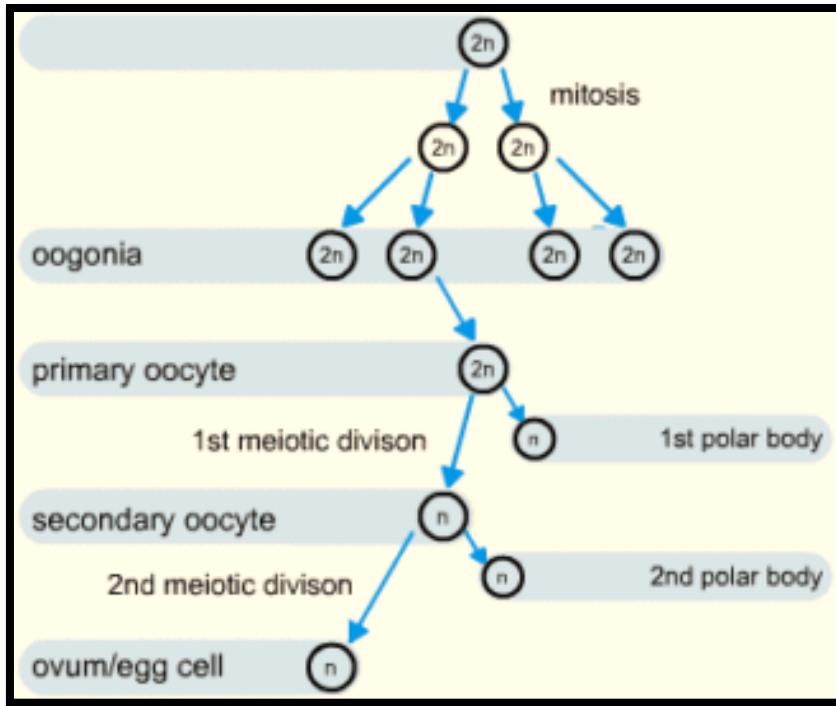
Oogenesis

Occurs in ovaries of female

Early cells stop meiosis and stay in Prophase I until puberty

One follicle will mature each month giving rise to a cell that has the potential to be fertilized.

Chapter 9 - Meiosis



Syngamy = fertilization which produces a zygote.

Points to Remember

Primary oocyte is diploid ($2N$)

Secondary oocyte is haploid (N), and it gets fertilized by sperm

★ Only if a sperm fertilizes the secondary oocyte will it resume Meiosis II.

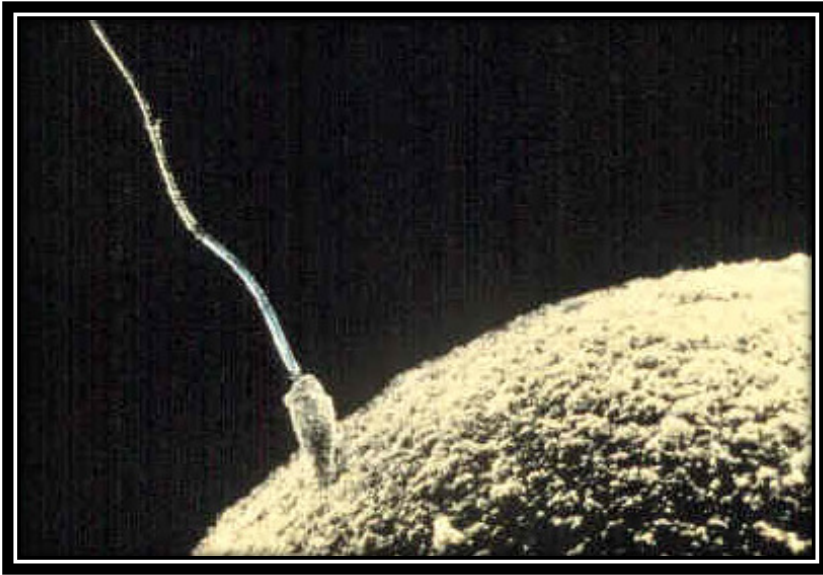
Polar bodies may eventually degenerate.

Why is a polar body made?

This small haploid cell generally cannot be fertilized. Polar bodies contain only a small % of the cytoplasm which was given to the daughter cell. Apoptosis usually is the final fate. Polar bodies eliminate half of the diploid chromosome set produced by the meiotic division. Much research is still being done by these “underappreciated” cells!

Chapter 9 - Meiosis

Many sperm cells reach the egg, only one will normally fertilize it.



Much still needs to be learned about the magical journey that a sperm must take before fertilization can occur. The functional maturation of the sperm is termed **capacitation**. This process must occur to render the sperm cell competent for fertilization. Many studies are still being done on capacitation. Studies have shown that capacitation allows the acrosomal reaction to take place.

I will discuss this reaction shortly.

Chapter 10 - Fertilization and Development

Fertilization and Development

Let's talk a little about fertilization. Studies on sea urchins gave us valuable information. The fertilization in sea urchins provide excellent information for similar events in vertebrates.

We need to prevent **polyspermy**, which normally leads to unsuccessful fertilization.

Exocytosis Occurs:

Upon contact with the jelly coat, this event is triggered. The tip of the sperm (acrosome) releases enzymes which digest this jelly coat.

Acrosomal Reaction:

Enzymes punch a "hole" in the jelly while growing actin filaments form from the acrosomal process. Binding to the egg cell receptors occur!!

Fast block to polyspermy:

Contact and fusion of sperm and egg now occurs. The membrane voltage now changes... **depolarization**. This results in what is called the fast block to polyspermy.

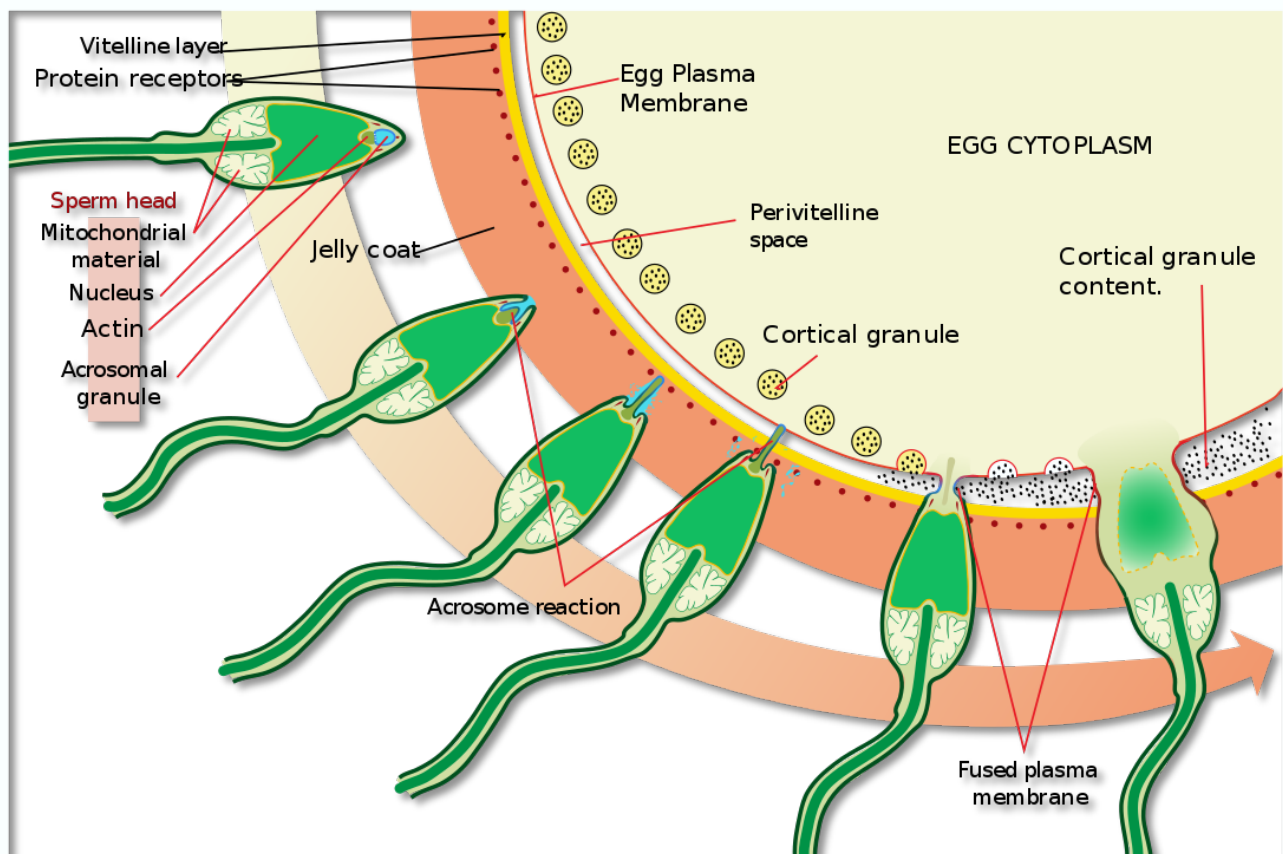
Cortical reaction:

Ca⁺⁺ ions are released from the endoplasmic reticulum... cortical granules in the egg fuse with the plasma membrane. Sperm-binding receptors are removed and a fertilization envelope forms. This forming of the fertilization envelope is termed the slow block to polyspermy.

Ca⁺⁺ is essential for the cortical reaction to occur.

★ Studies were done extensively on sea urchins, but this cortical reaction was also noted in mammals and fish!!

Chapter 10 - Fertilization and Development



Chapter 10 - Fertilization and Development

Fertilization in Mammals

Generally internal

Secretions in the female reproduction tract aid in sperm motility. Studies have shown that eggs release **progesterone**, which aids in motility!

Zona pellucida (extracellular egg matrix) contains sperm receptors

As we have seen, binding will allow for the **acrosomal reaction** to occur.

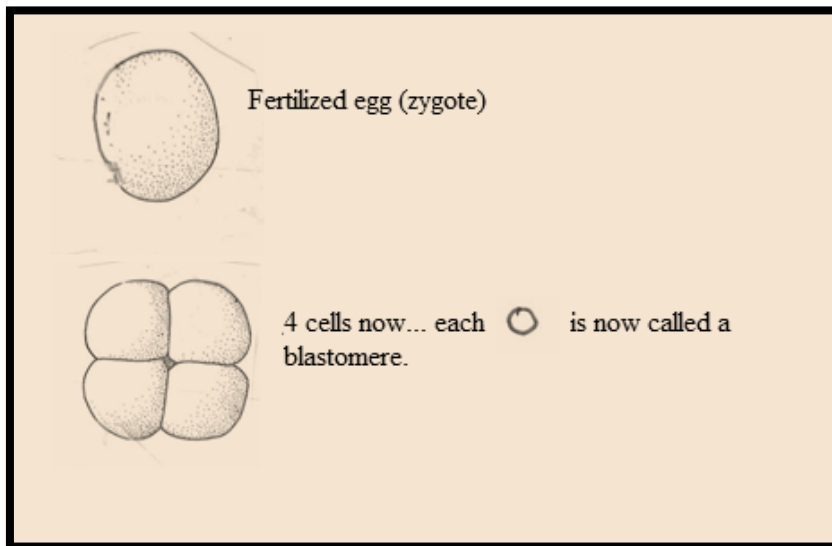
After fusion, the entire sperm is taken into the egg, but fertilization is slower in mammals than in sea urchins.

Once fertilization occurs, we see an event called **cleavage**.

This is a rapid period of mitosis, S and M phases of the cycle are carried out!

Cytoplasm is now divided or partitioned into smaller cells called **blastomeres**.

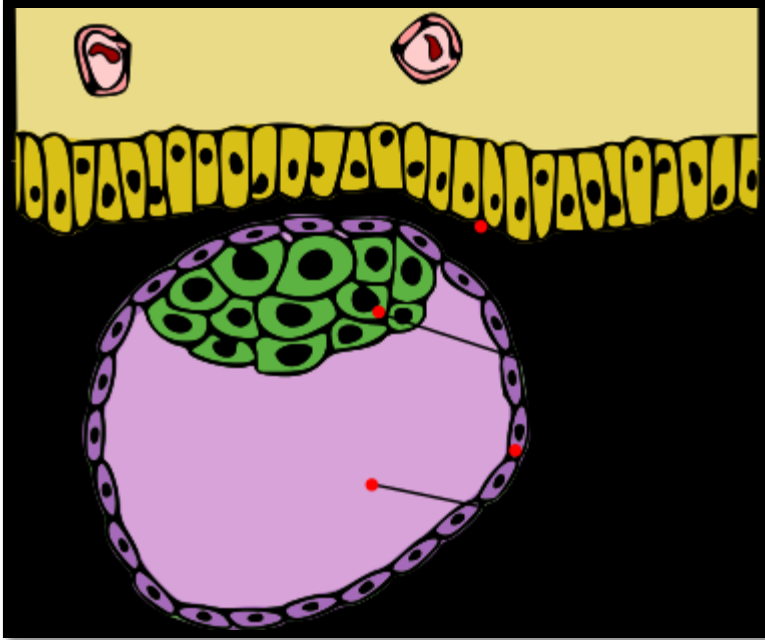
For example:



Continued cleavage gives a solid ball of cells called a **morula**. From here, a fluid-filled cavity called a **blastocoel** forms within this morula and begins to hollow. This hollow ball of cells is now called a **blastula**. (About 128 cells or 7 cleavages).

For example:

Chapter 10 - Fertilization and Development



★ Campbell's text has very nice pictures of this.

Note: In many animals, **yolk distribution** is the most important driving force that influences the cleavage pattern

Two poles are noted:

- a) **Vegetal Pole:** high in yolk
- b) **Animal Pole:** low in yolk

When sperm penetrates an egg, an enormous amount of structural reorganization occurs within the egg cytoplasm.

After cleavage, cell division slows... and the process called gastrulation occurs to form a **gastrula**.

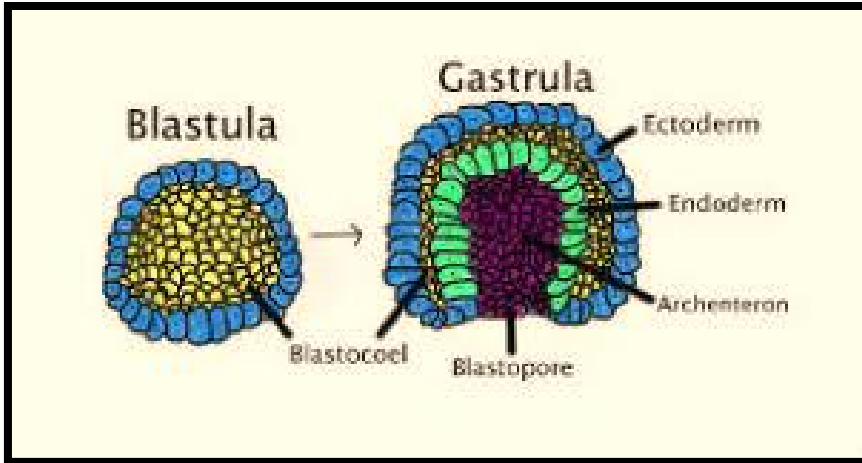
Three germ layers (endoderm, mesoderm, and ectoderm), result from gastrulation.

So far:

Zygote → Morula → Blastula → Gastrula

A new central cavity is formed called the **Archenteron**, which will become the primitive gut.

Chapter 10 - Fertilization and Development



The opening of the archenteron is called the **blastopore**. This opening forms the **mouth in protostomes** and **anus in deuterostomes**.

Protostomes include: mollusks, arthropods, and annelids

Deuterostomes include: chordates and echinoderms

For those that need a review:

Chapter 10 - Fertilization and Development

Mollusks



Snails, oysters, clams, squids, octopuses

Marine organisms

Most have hard shells... CaCO_3 !

Most have an open circulatory system where fluid called hemolymph moves in cavities and sinuses

Coelomates (have a body cavity)

Arthropods



Most successful of all animal phyla and the largest!!

Insects are here

Chapter 10 - Fertilization and Development

Crustaceans like crayfish, lobster, shrimp

Spiders, scorpions, mites, millipedes, etc.

Segmented bodies, efficient nervous system and sensory organs

Hard chitinous exoskeleton... can be shed (molting)

★ Jointed appendages: this really allowed them success!! They can use these jointed appendages to move from predators, hunt for food, and fight!!

Have eyes with thousands of photoreceptors

Open circulatory system

Most insects use tracheal systems for gas exchange

★ Grasshoppers use Malpighian tubules to aid in metabolic waste removal

Annelids



Think worms!!

Closed circulatory system (blood moves through vessels)

Have segmentation

Use setae to move, which provide the traction they need to crawl and burrow through soil

Have ganglia... cluster of nerve cells that is involved for control of local activity

Nephridia... functional unit of excretion, regulates body fluid composition and volumes

Remember: Arthropods, annelids, and mollusks are protostomes... mouth forms first, anus forms second.

Chapter 10 - Fertilization and Development

Echinoderms



These are deuterostomes: anus forms first, followed by mouth formation

Sea stars, sea urchins, sea cucumbers

★ Have radial symmetry... symmetry in all directions

Nervous system is decentralized; no brain!!

Decentralization is advantageous for animals with radial symmetry since it allows them to avoid predators from different directions.

Unique to them is a water vascular system which is a series of canals that are involved with movement (locomotion), gas exchange, and even attaining food sources.

Chapter 10 - Fertilization and Development

Chordates



Fish, amphibians, birds, mammals, reptiles, tunicates and lancelets

Bilateral symmetry

Have a notochord: provides skeletal support

Dorsal hollow nerve chord... unique to chordates. Develops into the brain and spinal cord

Pharyngeal gill slits, for gas exchange

★ In humans, the notochord becomes a gelatinous disk found between vertebrae

Muscular, post-anal tail

★ Tunicates and amphioxus are classified as chordates, but are invertebrates

A few helpful things for the DAT

Chapter 10 - Fertilization and Development

Cnidaria



Hydras, jellyfish, corals, sea anemones

Unique stinging cells called nematocytes!!

Painful stings result

A single cnidarian tentacle could contain thousands of nematocysts!!

Chapter 10 - Fertilization and Development

Platyhelminthes



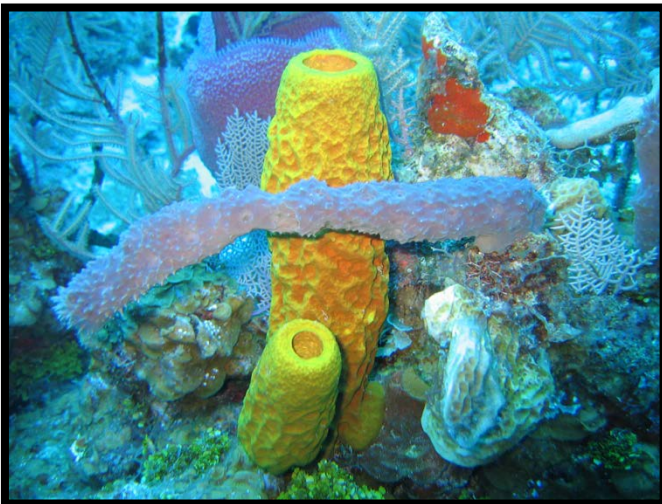
Are flatworms like tapeworms and flukes

Unsegmented

Acoelomates: a solid body animal lacking a body cavity

(A coelomate, like vertebrates have a body cavity that is derived from mesoderm).

Porifera



Includes sponges: have choanocytes to trap food

Chapter 10 - Fertilization and Development

Nematode



Includes hookworms and pinworms (round worms)

They are classified as pseudocoelomates

No circulatory system

Coelomates: mollusks, annelids, arthropods, echinoderms, mammals, chordates

Acoelomates: Platyhelminthes

Pseudocoelomates: nematodes

Chapter 10 - Fertilization and Development

Amphibians



Half-aquatic, half-terrestrial

★ Evolved from lobe-finned fish (many live in brackish, salty, water such as in coastal wetlands)

Frogs, salamanders, toads, newts, and caecilians

Most are found in damp areas such as swamps

Rely heavily on moist skin for gas exchange some even lack lungs and this moist skin is essential

External fertilization: egg and sperm are discharged into the environment

Eggs are laid in water, male then fertilizes them

Lack an amnion!!

Closed circulatory system

Three chambered heart (2 atria, 1 ventricle)

Chapter 10 - Fertilization and Development

Reptiles



Turtles, crocodilians, lizards, snakes (more than 90% are snakes and lizards)

Closed circulatory system

Bony exoskeleton and scaly skin

Have an amnion... included as a member of the amniotes

As amniotes, they have a terrestrially adapted egg.

Internal fertilization

Most have 3 chambered heart... crocodilians and alligators have 4!!

Birds descend from reptiles during the Jurassic times. The Jurassic period was part of the Mesozoic Era!

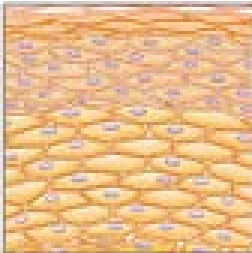
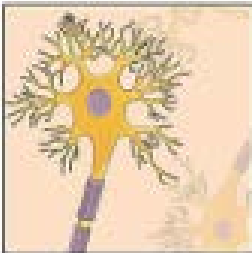
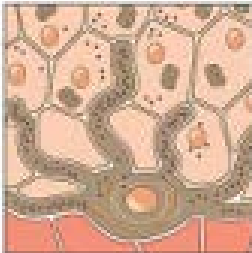
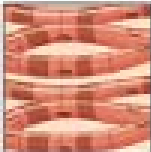
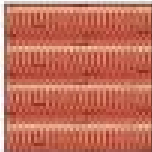
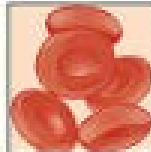
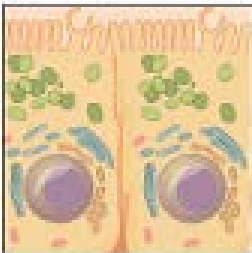
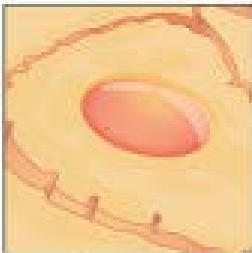
Fun Fact:

Dinosaurs came in Jurassic Period which was part of the Mesozoic Era

Most Modern Era: Cenozoic Era

Chapter 10 - Fertilization and Development

Three Germ Layers

Germ Layer	Gives rise to:
Ectoderm	Epidermis, glands on skin, some cranial bones, pituitary and adrenal medulla, the nervous system, the mouth between cheek and gums, the anus    Skin cells Neurons Pigment cell
Mesoderm	Connective tissues proper, bone, cartilage, blood, endothelium of blood vessels, muscle, synovial membranes, serous membranes lining body cavities, kidneys, lining of gonads      Cardiac muscle Skeletal muscle Tubule cell of kidney Red blood cells Smooth muscle
Endoderm	Lining of airways and digestive system except the mouth and distal part of digestive system (rectum and anal canal); glands (digestive glands, endocrine glands, adrenal cortex)    Lung cell Thyroid cell Pancreatic cell

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Let us now return to the gastrula. Recall, we have formed our three germ layers:

Chapter 10 - Fertilization and Development

Endoderm:

Epithelial linings of respiratory, excretory, and digestive tracts, urinary bladder, and lining of reproductive systems and urethra

Glands such as thymus, thyroid, parathyroid

Liver and pancreas

Mesoderm:

Bone

Muscle

Blood

Connective tissues!!

Notochord

Excretory, lymphatic, and excretory system

Dermis of skin

Adrenal cortex

Ectoderm:

Outermost layer- most sensitive to radiation!!

Skin

Nails

Hair

Sweat glands

Tooth enamel

Cornea and lens of the eye

Adrenal medulla

Organogenesis

Now that we have the three germ layers, now what?

We see **organogenesis!!!**

Movement of cells occurred in gastrulation, note the U-shaped structure. In organogenesis we see more of a shape change.

As organogenesis progresses, morphogenesis (think shape) and cell differentiation continue.

Chapter 10 - Fertilization and Development

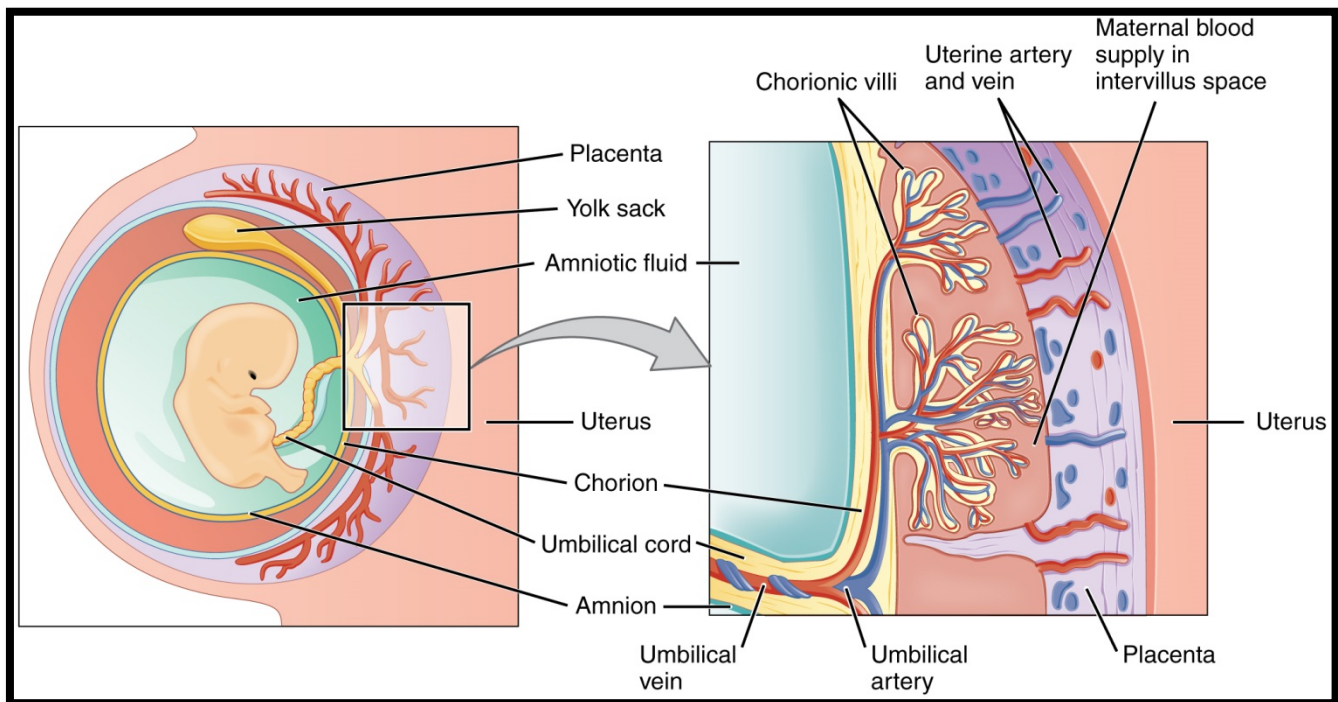
The greatest changes in cell shape and cell position occur in gastrulation and organogenesis.

The DAT Destroyer will reinforce these concepts, but this is a great base for you to have! Our new edition has many new problems reflecting new DAT trends.

During organogenesis in vertebrates, a few points to remember:

1. Condensing of mesoderm gives rise to the notochord. This is a rod of stiffened tissue that serves as a support-like structure in all chordates.
2. Neural plate forms from the ectoderm and rolls into the neural tube which becomes the central nervous system... brain and spinal cord.
3. Somites are formed... they represent blocks of mesoderm which give rise to vertebrae and muscle. Somites are arranged along the notochord.

Amniotes



Birds, reptiles, and mammals are here

All contain a fluid-filled sac called an amnion

Extraembryonic membranes:

Found in most shelled eggs!

Located outside the embryo:

- 1) Yolk sac
- 2) Amnion

Chapter 10 - Fertilization and Development

- 3) Chorion
- 4) Allantois

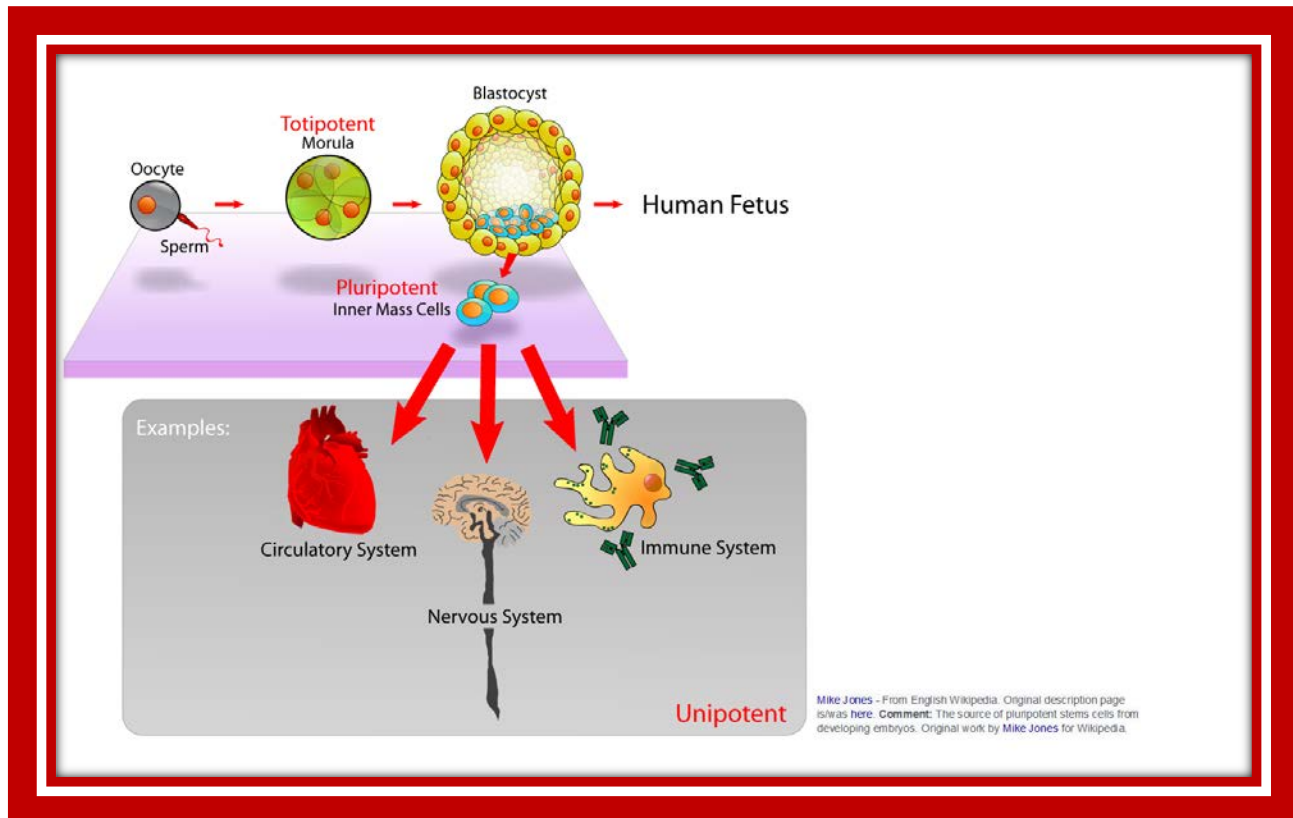
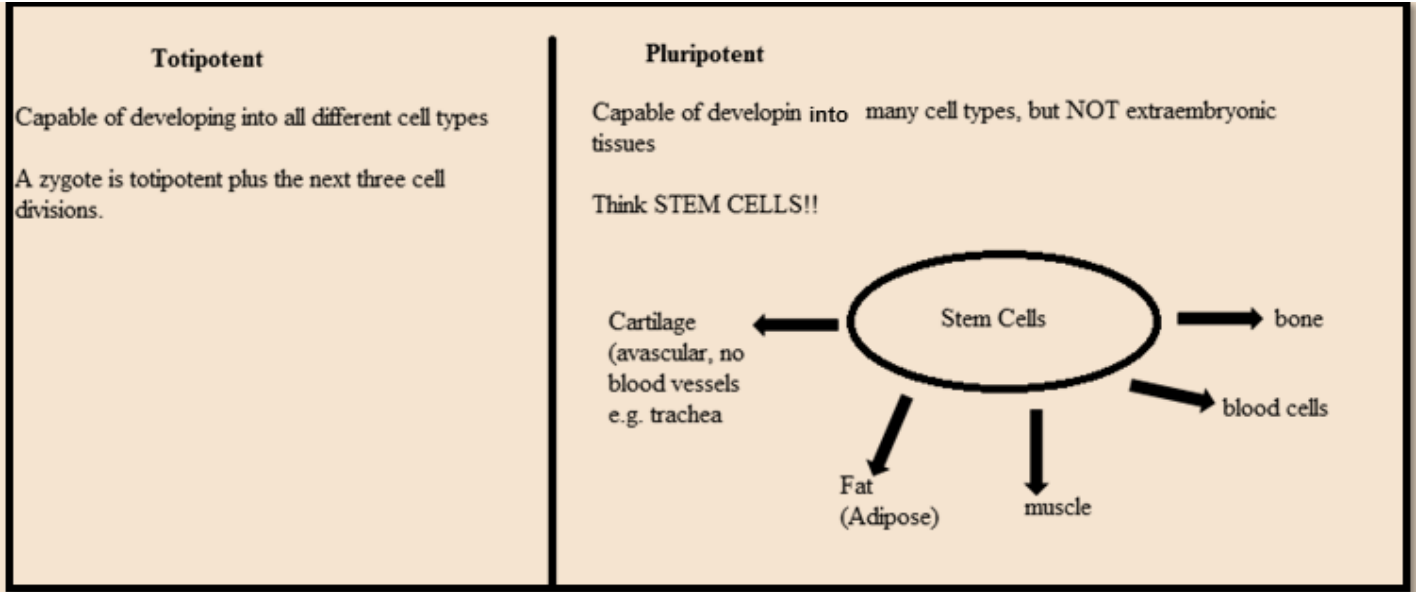
Yolk sac: encloses the yolk; provides needed nutrients

Chorion: gas exchange, forms part of the placenta

Amnion: absorbs shocks, keeps embryo from drying out

Allantois: disposes of nitrogen waste and gas exchange. In humans it does not store wastes, but is involved in O₂ and nutrient transport.

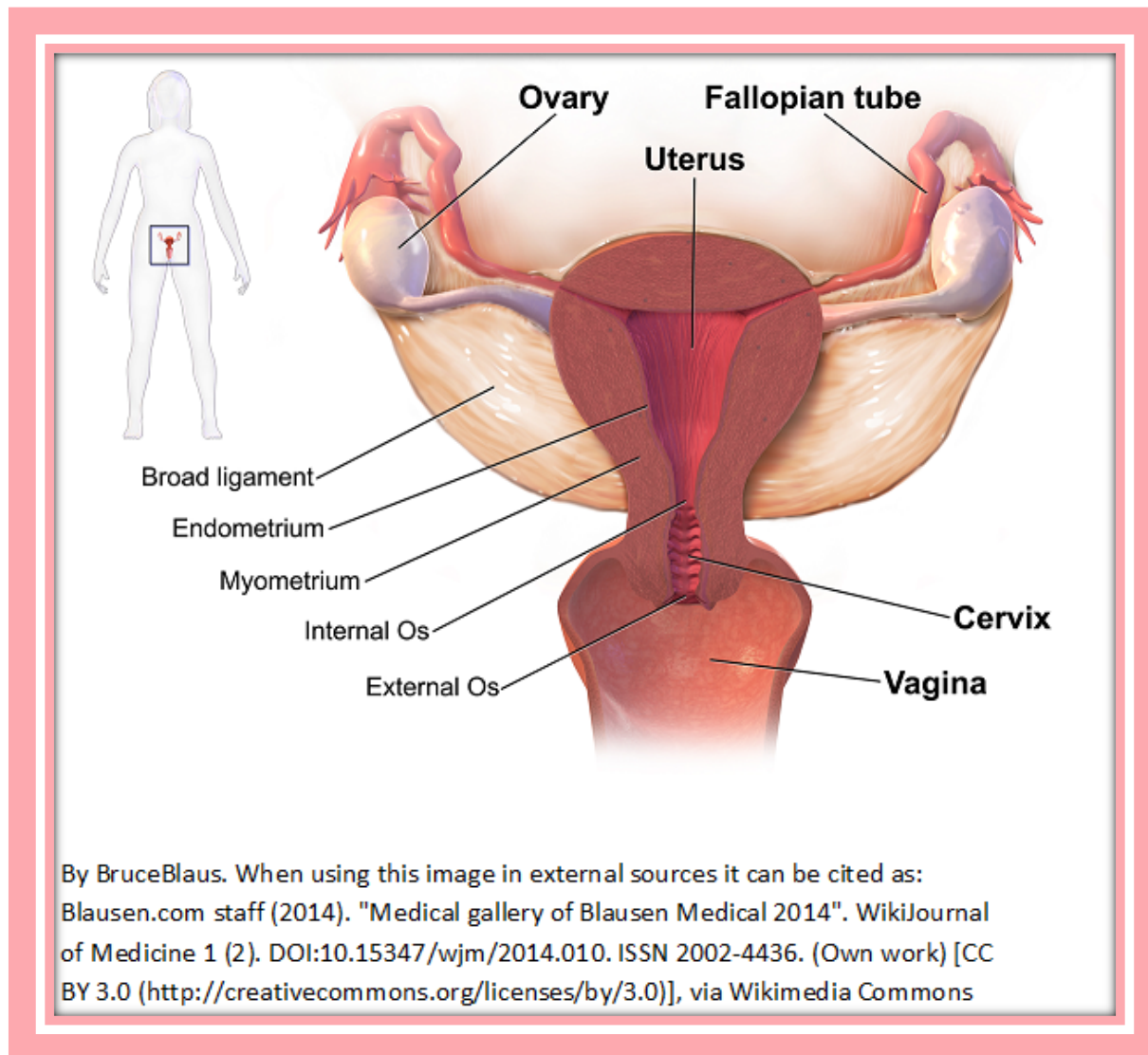
Chapter 10 - Fertilization and Development



Chapter 10 - Fertilization and Development

Fertilization in Humans

Fallopian tube (oviduct)



Implantation occurs in the **endometrium** of the uterus and occurs before the end of the first week.

★ **The blastocyst is what adheres to the endometrium. The blastocyst is the mammalian version of a blastula.**

In contrast to birds, reptiles, and monotremes (an egg laying mammal like a platypus), the mammalian egg is smaller. A human embryo is not housed in a shell, nor nourished by yolk, but does have a yolk sac. This sac plays a role in forming the digestive tract.

Chapter 10 - Fertilization and Development

An umbilical cord will connect the human embryo to parts of the yolk sac, allantois, and amnion. The umbilical cord is well-endowed with blood vessels. The chorion develops around the embryo and secretes the hormone chorionic gonadotropin hormone that will be responsible for maintaining the corpus luteum. The corpus luteum secretes progesterone during the first three months of pregnancy (trimester 1). After the first three months, the placenta takes over to produce sufficient progesterone and estrogen (steroid hormones).

Human gestation can be divided into three trimesters:

Trimester #1

The first three months

Most growth and differentiation occur here

Most sensitive to radiation and drug toxicity



Main period for organogenesis



After eight weeks, the embryo is called a fetus

Outer layer of the blastocyst called the **trophoblast** grows within the endometrium to form the placenta.



A **viviparous** development in means the young are born alive after being nourished in the uterus from the placenta...**oviparous**, in contrast means the young hatch from eggs laid outside the mother!!

Trimester #2

Months 4,5,6

Further growth occurs; all major organs formed

Pregnancy is now obvious

Corpus luteum now deteriorates as levels of hCG decrease since placenta now takes over the role of making progesterone and estrogen.

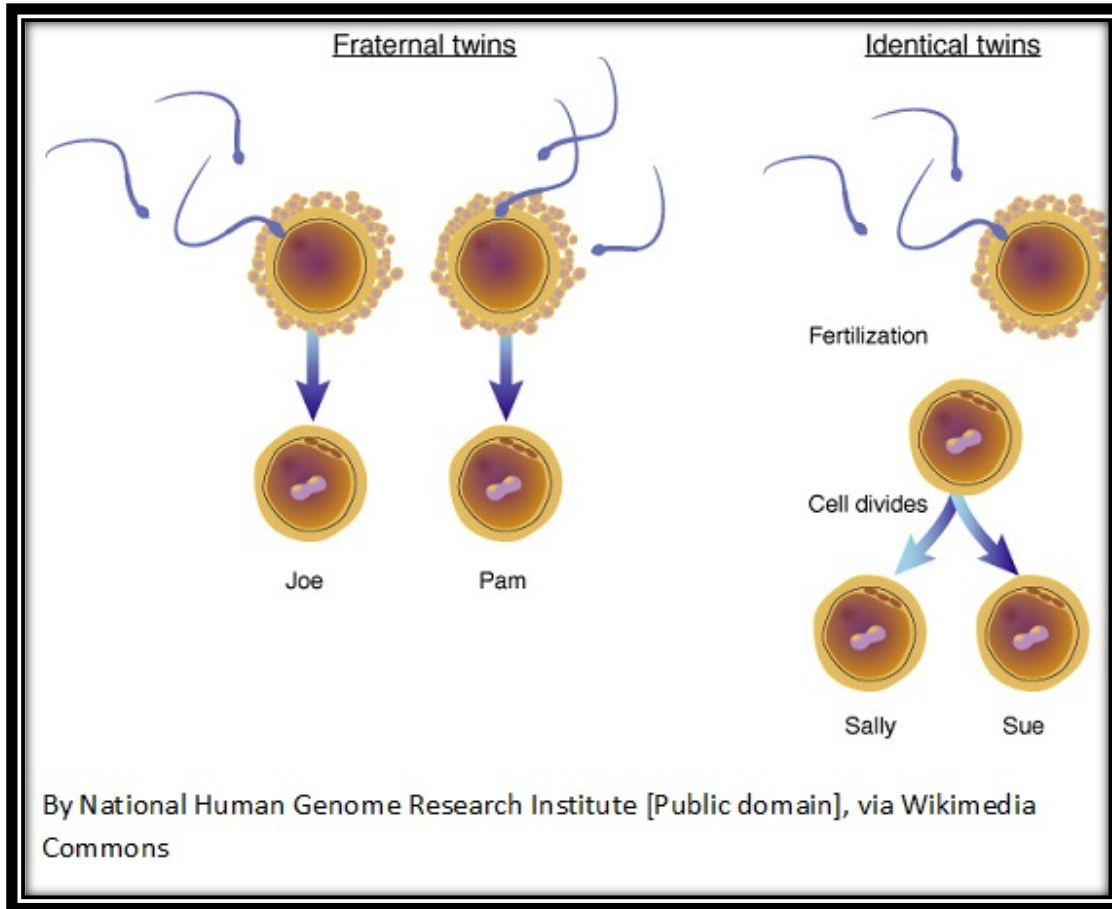
Trimester #3

Months 7, 8, 9

About 8 months the fetus can survive on its own!! However, with medical care I have read reports of fetuses as young as 23 weeks make it alive!!

By around month 9... you pop out!

Chapter 10 - Fertilization and Development



Summary of human development:

Zygote → Morula → Blastocyst → Embryo → Fetus

What is a homeotic gene?

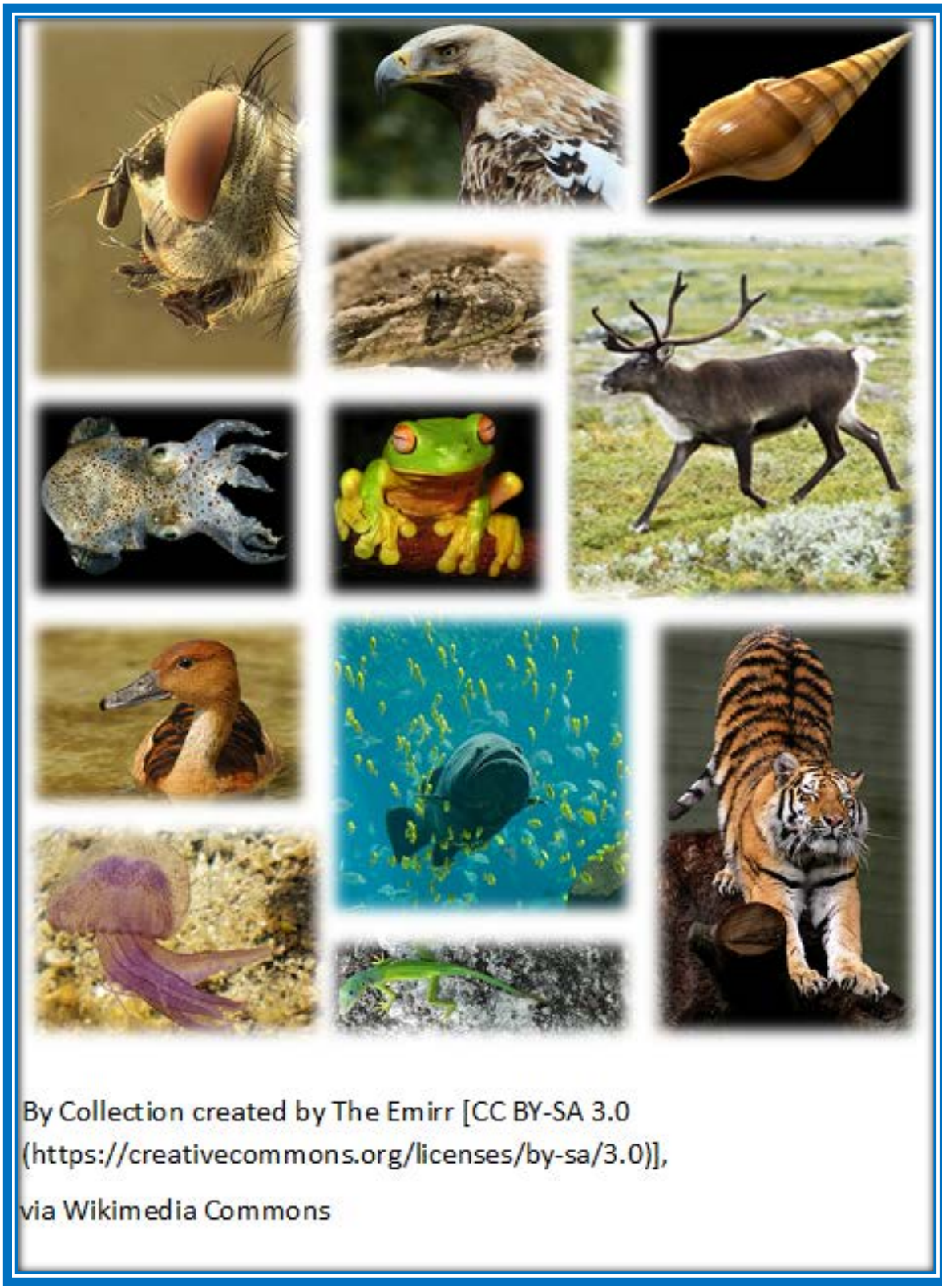
These are regulatory genes that are responsible for the placement and spatial organization of body parts in animals, plants, and even fungi!! These homeotic genes control the development and the fate of many cell groups.

For example, a homeotic mutation may affect the regulatory gene involved with the development of an antenna. Instead of developing into an antenna, a leg is made!!

I have put many challenging problems in the DAT Destroyer. Make sure that you read all the wrong answers and know my explanations. The DAT loves the area of embryology! Make sure you understand clearly all that I have outlined here! Know every problem in my book!!

Chapter 11 - Biodiversity

Biodiversity



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Chapter 11 - Biodiversity

The evolutionary history of a species or even a group of related species is termed **phylogeny**. In **taxonomy**, organisms are put into categories based on similarities and differences.

Hierarchical classification:

1. Domain... (Bacteria, Eukarya, Archae) Bacteria and Archae contain prokaryotes!!
2. Kingdom
3. Phylum
4. Class
5. Order
6. Family
7. Genus
8. Species (can interbreed)

★ Binomial nomenclature developed by C. Linnaeus...

A polar bear is *Ursus maritimus*. (Genus, Species).

A grizzly bear is *Ursus horribilis*.

What is a phylogenetic tree?

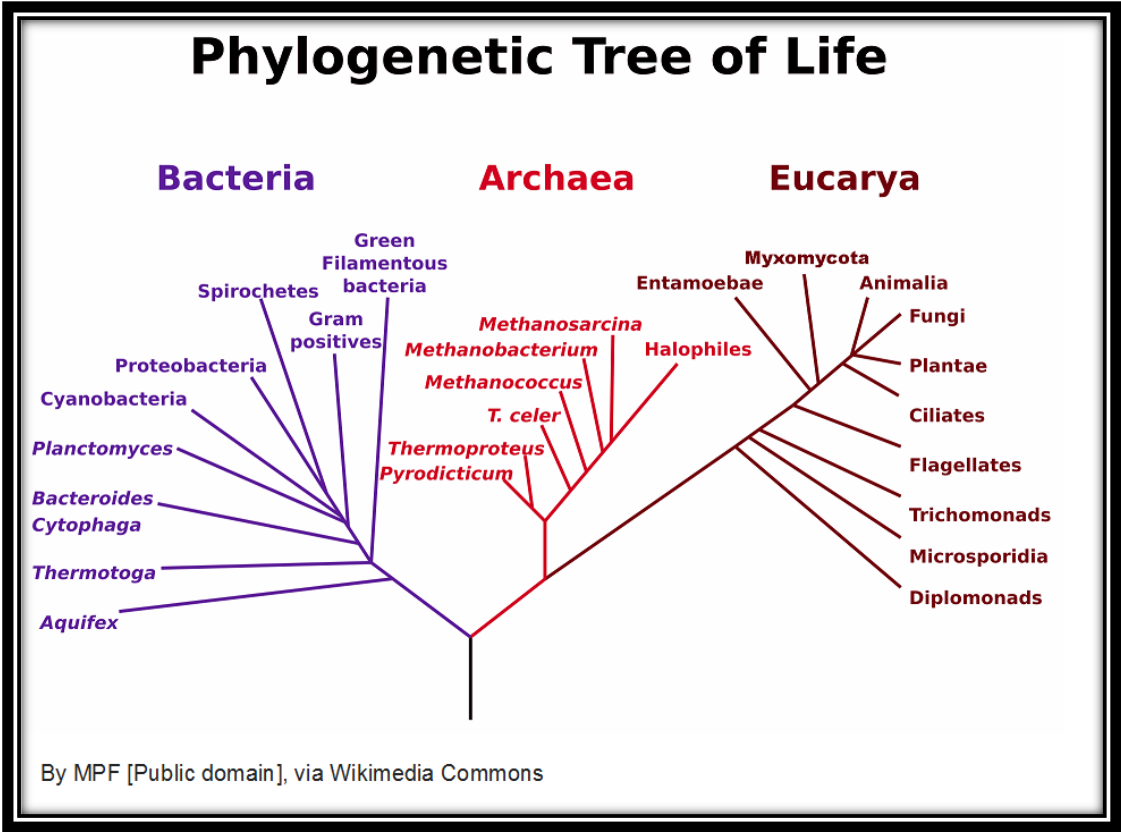
This is a representation of the evolutionary history of a group of organisms.

A **clade** is a group of organisms that will include an ancestor and the descendants of that ancestor.

The tree is built according to morphology, genetic, and behavioral traits of an organism.

The phylogenetic tree helps us to understand how various functions evolved, and to study the lineage of various species.

Chapter 11 - Biodiversity



The cladogram or phylogenetic tree is basically a diagram in which the branches show the history of evolution.

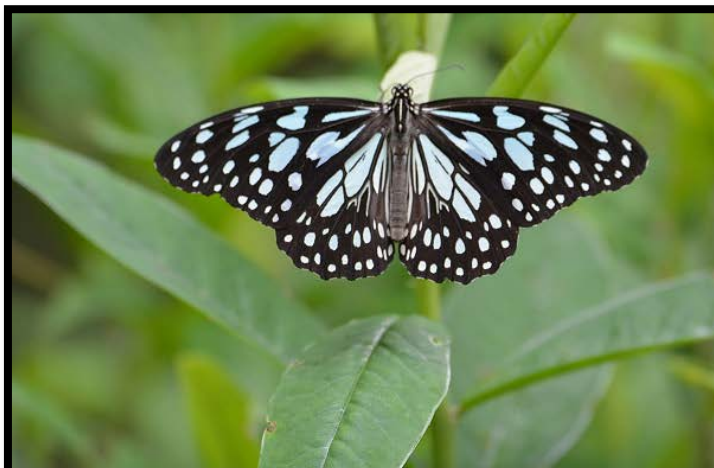
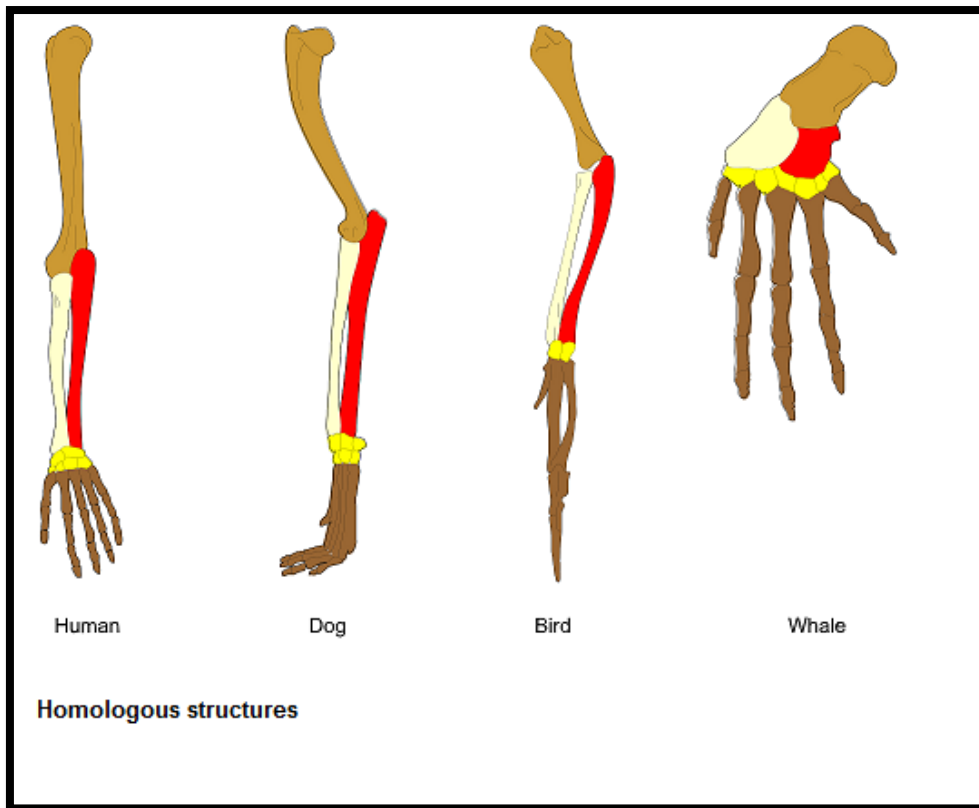
A few useful terms:

Homologous Structures	Analogous Structures
Share a common ancestor	No common ancestor
Structures may resemble one another (similar anatomy, morphology, embryology, etc.)	Similar appearance and structure
Arms, forelegs, flippers, wings e.g. wing of a bat and the flipper of a whale and leg of a dog Arm of a man and wing of a bird Function varies widely!!	Perform the <u>same</u> function e.g. fins of a fish and flippers of a whale e.g. wing of a dragonfly and wing of a bird Notice the wings do look alike and perform the same function <u>but</u> show no homology (no ancestor)
Morphological Divergence!!!	
They might <u>not</u> perform the same function	



Chapter 11 - Biodiversity

This is a big DAT topic!!



The wing of a butterfly and the wing of a bird represent analogous structures.

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Chapter 11 - Biodiversity

Molecular Clocks

Are methods employed to measure evolutionary change.

It is based on the idea that some genes and regions of genomes appear to evolve at constant rates.

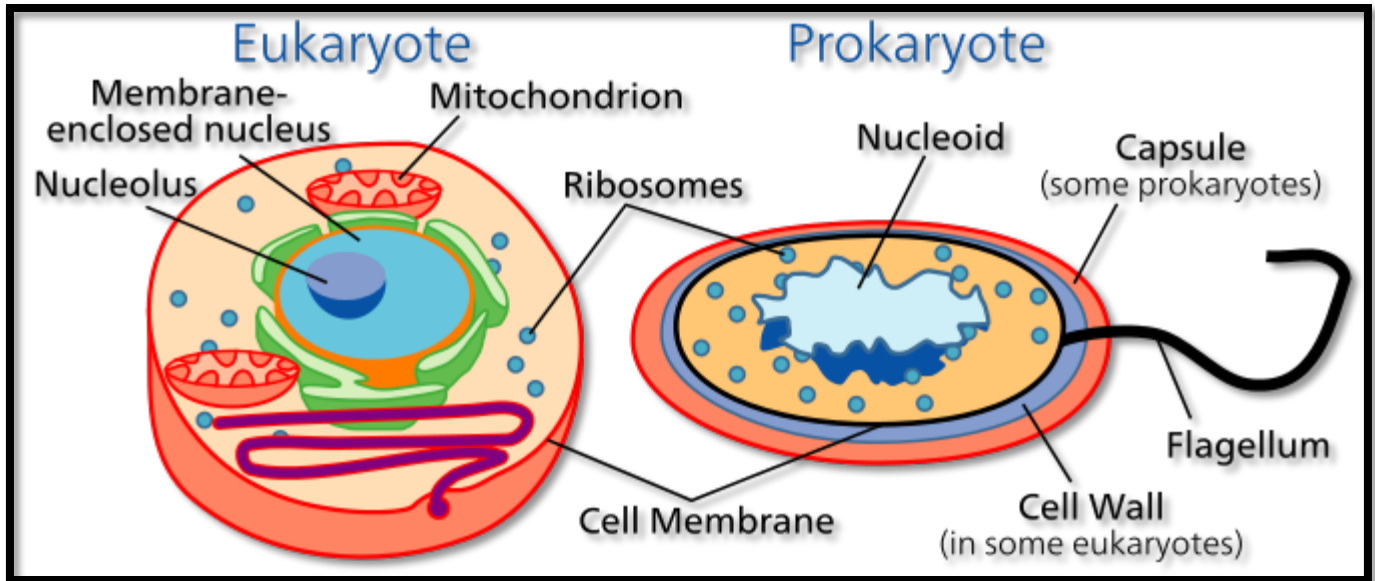
Some genes will evolve thousands or even million times faster than others.

In this technique, mutation rates can be noted and conclusions about when two or more life forms diverged... DNA is usually studied for analysis.

A nice paper was done by Simon Ho, PhD, from Australia National University for those who would like further information.

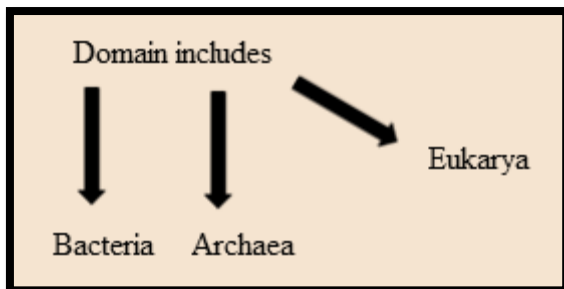
Eukaryotes	Prokaryotes
Nucleus houses the genetic material	No nucleus, but has DNA and RNA
Cytosol	Cytosol... has DNA floating in it! This region is called a nucleoid...
Ribosomes present	Ribosomes present
Golgi, Endoplasmic Reticulum, Lysosomes, Vacuole, Mitochondria, Chloroplasts (if plants), peroxisomes are present	Smaller than eukaryote cell, no cell organelles like Golgi, ER, Lysosomes, etc.
Cytoskeleton present: Microtubules: thickest! Microfilaments: thinnest!!!! Intermediate fibers	Flagellum present
Plasma membrane	Rudimentary cytoskeleton
Nucleolus	Lacks membrane-bound organelles
Cell walls if in fungi, protists, plants but not in animal cells	No nucleolus
Animals, insects, hydra, paramecium (single celled however), Amoeba (single celled usually), yeast, plants, mushrooms, fruit flies, etc. etc.!!	No chloroplasts
	Single celled!!
	Bacteria and Archae are here!!

Chapter 11 - Biodiversity



Note: When I was in college we were taught the five kingdoms... Monera, Fungi, Plantae, Animalia, and Protista... they now added what is called a domain.

This taxonomic category is above the kingdom!!



Chapter 11 - Biodiversity

Bacteria, Archaea, and Viruses

Prokaryotes were the first organisms believed to inhabit the Earth.

Anaerobic heterotrophic prokaryotes were the first to inhabit the Earth.

Earth is about **4.5 billion years old**

Prokaryotes came about **3.5 billion years**

Eukaryotes came about **2.5 billion years** (newer 2017 estimate)

I make damn sure my students know these three timelines.

Prokaryotes are usually much smaller than eukaryotes. (I compared and contrasted them previously for you).

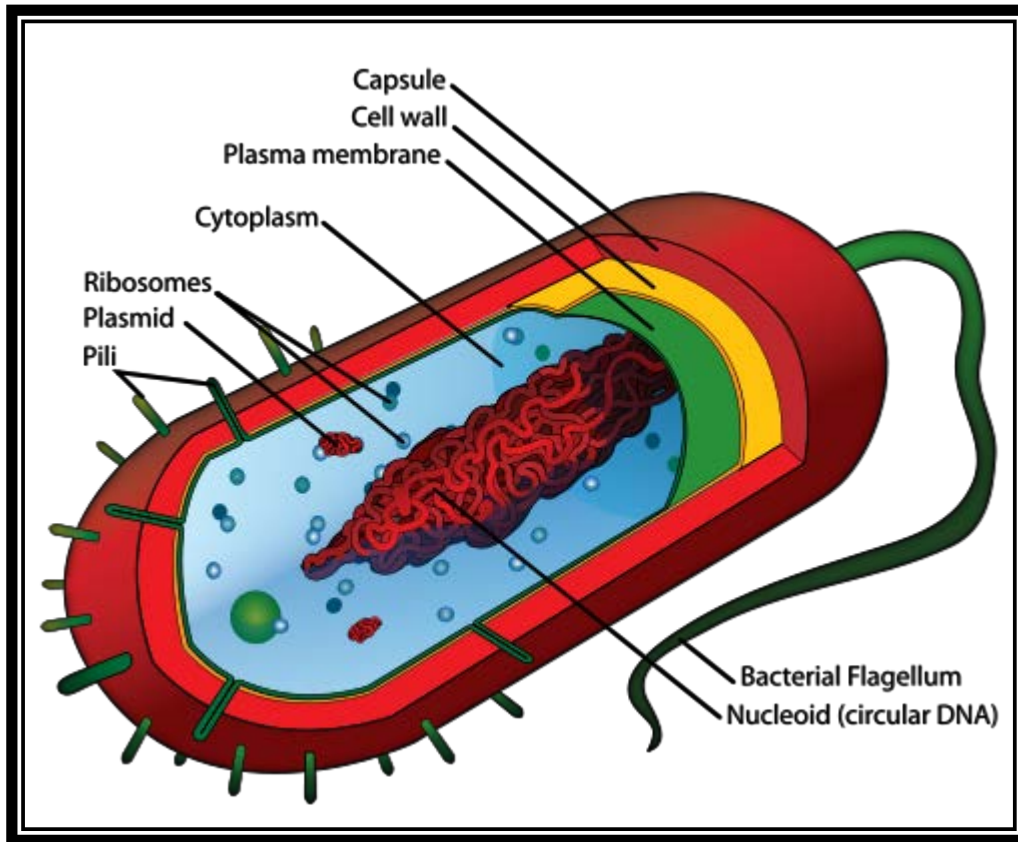
Low O₂ levels likely is a major reason that it took so long for eukaryotes to evolve.

Early Earth had a **reducing atmosphere** that lacked O₂!!! A reducing atmosphere contained CH₄, H₂O vapor, H₂, CO, and HCN.

How did Earth gain O₂? Partly because **Cyanobacteria** (Blue-Green algae) were able to conduct photosynthesis and gave off O₂!! Studies are still going on to understand the details.

Chapter 11 - Biodiversity

Prokaryotes



Most prokaryotes are unicellular.

Display a range of shapes:

Coccus:

May be in pairs or singly (diplococci)

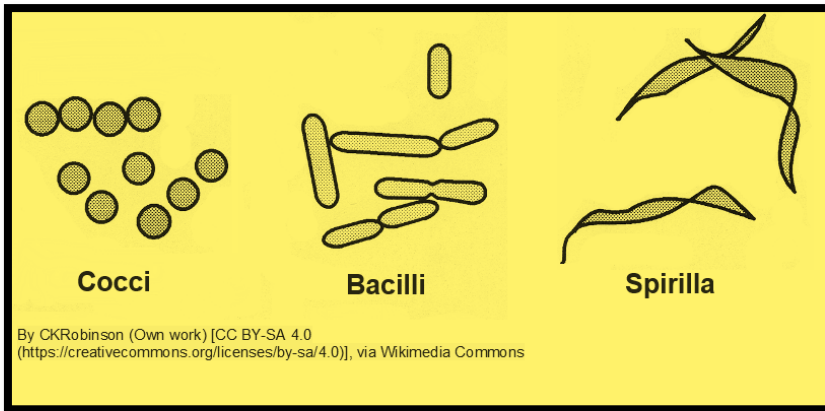
May be in chains (streptococci)

May be in clusters (staphylococci)

Chapter 11 - Biodiversity

Bacilli: rod shaped

Spiral



Prokaryotes belong to kingdom **Monera**

Prokaryotes divide by **binary fission**... asexual!

Highly successful because they can reproduce rapidly given favorable conditions. A new generation can appear in under a half hour!!

Many use flagella to move and exhibit **taxis** toward or away from a stimulus

+ Chemotaxis... e.g. bacteria moves toward food

- Chemotaxis... e.g. bacteria moves away from a toxic chemical

Prokaryotic flagella and eukaryotic flagella are a nice example of analogous structures.

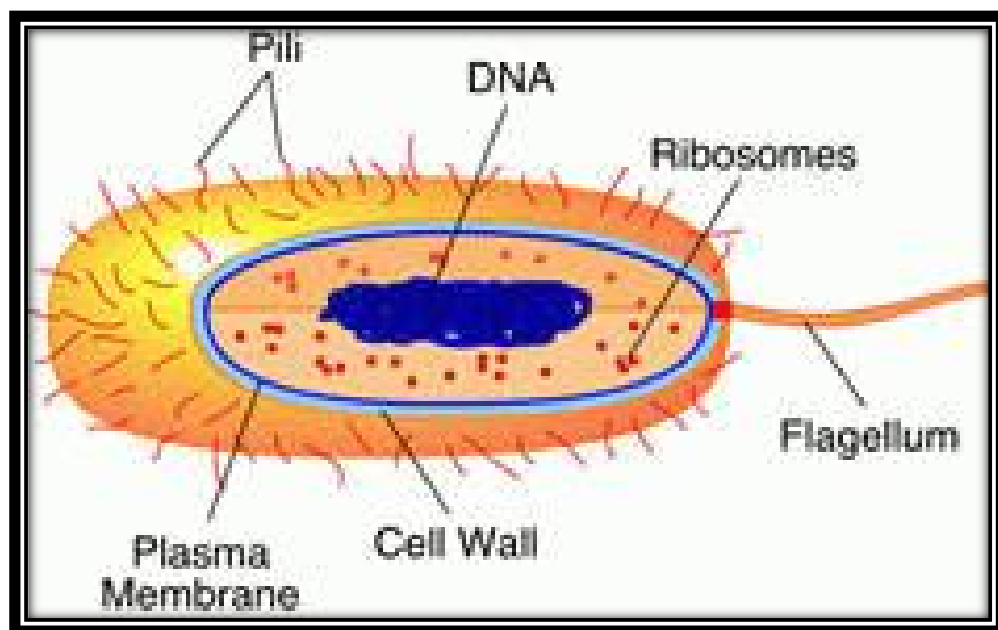
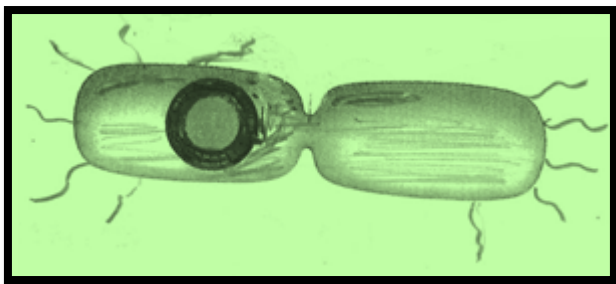
Many ribosomes are present; a plasma membrane mediates the flow of material. Channels, proteins, receptors, and transporters are all present.

★ Clearly you now see that bacteria (prokaryotes) are not so simple after all.

No 9+2 structure is noted for the flagella, as was seen with eukaryotes.

Chapter 11 - Biodiversity

Pilli are protein filaments used to attach to cell surfaces or even to one another during **conjugation**.



Note the conjugation tube pilus connecting them... as well as the pilli extensions!

What is the circular object? This is the **plasmid**, which is a small, self-replicating circular piece of DNA.

Chapter 11 - Biodiversity

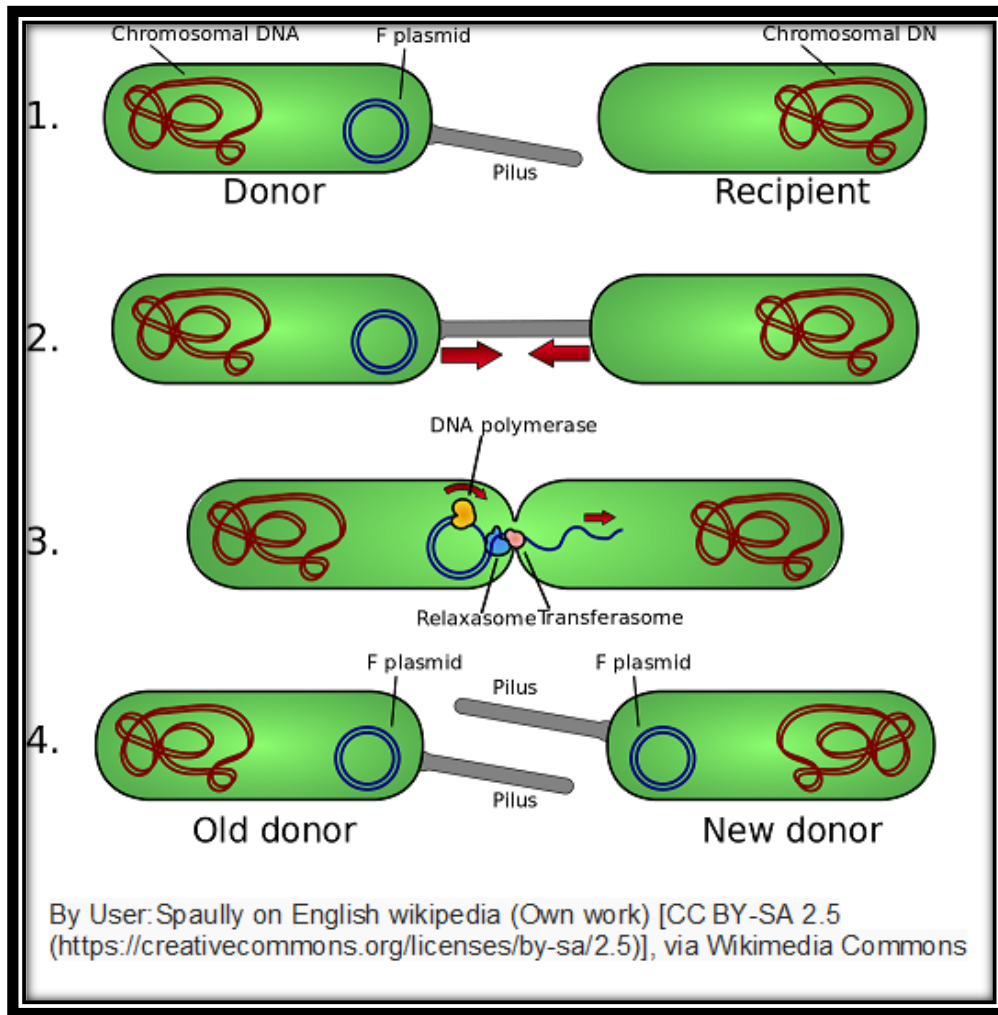
Plasmids

Carries accessory genes separate from the bacterial chromosome

Contains genes (at least one, often hundreds) that can benefit the organism... think **drug resistance**!

F-Plasmids: contain genes that allow for conjugation

R-Plasmids: contains genes for resistance against poisons or antibiotics



Mutualism

Bacteria can serve good purposes...

For example, bacteria in the human large intestine, namely *E. coli* can help form Vitamin K.

This symbiosis is called mutualism. We allow them to live (host), they help to make Vitamin K.

Recall:

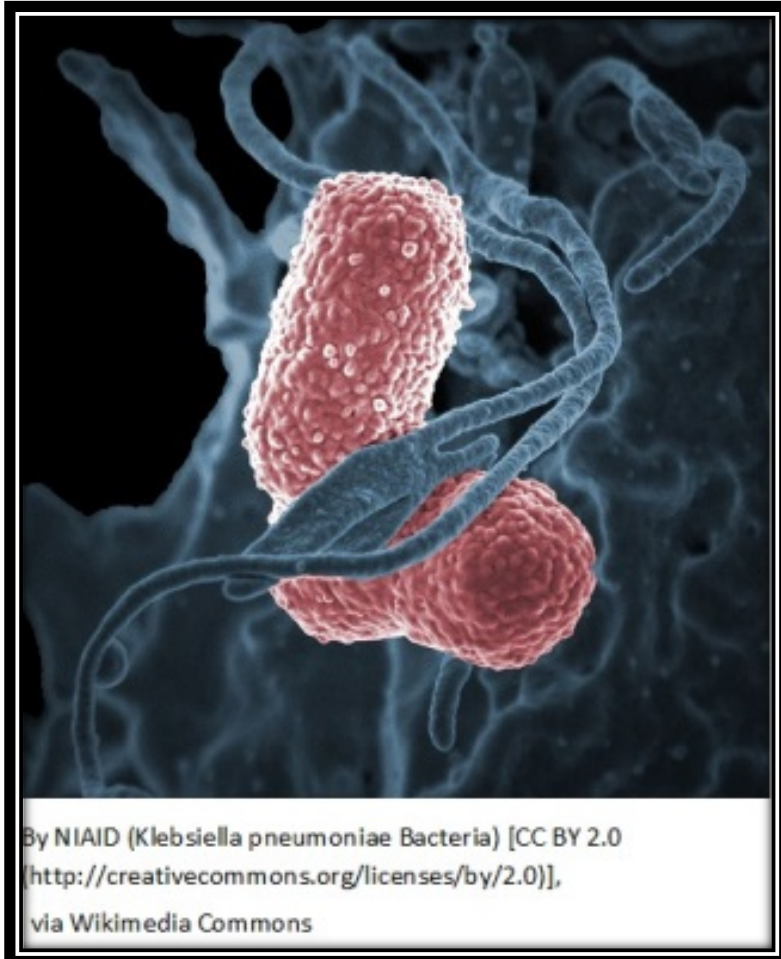
Vitamins A, D, E, K... Fat soluble

Chapter 11 - Biodiversity

Vitamins B, C... H₂O soluble

★ Vitamins do not produce ATP for energy!!

Bacterial Diseases



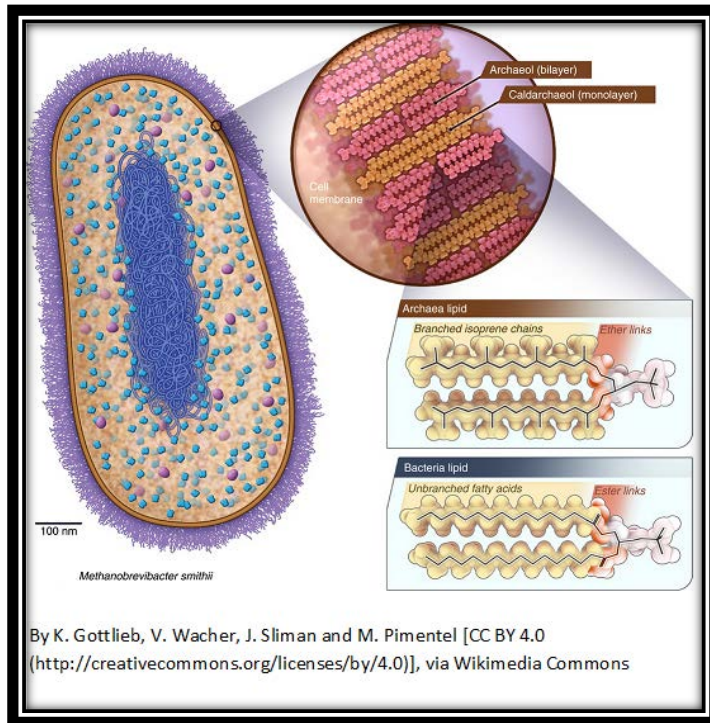
Bacterial Diseases include:

- a) Anthrax
- b) Sepsis
- c) Salmonellosis... food poisoning
- d) Leprosy
- e) Syphilis
- f) Gonorrhea

Useful for the DAT exam!!

Chapter 11 - Biodiversity

Archaea



Another type of organism classified with the Prokaryotes are the Archaeobacteria or Archaea.

Include three major groups

Thermophiles:

Love heat... live in sulfur-rich hot springs

Almost all are obligate anaerobes... they die if exposed to O₂. S is their electron donor or acceptor.

Methanogens:

Make CH₄ gas

Live in swamps

★ Live in stomach of **ruminants** like cows... Recall Ruminants can digest cellulose (the β-1,4-linkage is broken and glucose released) ... they contain the microorganisms (bacteria, fungi, etc.)

Cocci and rod-shaped organisms are noted

They are chemoautotrophs: use H₂ as an electron source for reducing CO₂ to CH₄ gas!!

Extreme Halophiles:

They love salty (brackish) habitats such as the Dead Sea.

Most produce ATP aerobically, but when O₂ is low some strains use sunlight for photosynthesis.

Chapter 11 - Biodiversity

How is energy produced?

They carry out glycolysis (anaerobic process) and are capable of additional reactions.

They are able to use an electron transport chain to make ATP!

Anaerobic bacteria live by using different electron acceptors such as NO_3^- or SO_4^{2-} at the end of their electron transport chains.

Phototrophs obtain their energy from sunlight

Prokaryotes decompose plants and animals which returns CO_2 to the atmosphere

Methanogens produce CH_4 which can eventually be oxidized to CO_2 . Clearly, they are vital to the **Carbon Cycle**.

They also “fix” atmospheric N_2 , where it is converted into NH_3 . Nitrogen fixation is essential for the biosynthesis of essential molecules in plants and other life forms. Their role in the **Nitrogen cycle** is enormous.

The Nitrogen-fixing bacteria are found in the **root nodules**!!

Gram + and Gram - Bacteria

Let us examine the Gram + and the Gram – bacteria

Gram -	Gram +
Thin peptidoglycan layer that poorly stains red or pink, but when washed with alcohol solution does not retain it.	Thick peptidoglycan layer that stains purple and retains the stain when washed with alcohol solution.
No Teichoic acids	Usually present for Teichoic Acids (provides rigidity to cell wall, and provides binding sites for cations).
Has an outer membrane	No outer membrane
High Lipids and Lipoprotein	Low amount of Lipid and Lipoprotein
★ More resistant to antibiotics due to outer membrane	Less resistant, thus more susceptible to antibiotics
Can be pathogenic	Can be pathogenic

★ Archae are not pathogenic ★

Taking too many antibiotics or the wrong dosage can cause the development of resistant bacteria as well as killing of bacteria that are helpful!

Chapter 11 - Biodiversity

Viruses

No cells- no organelles!!

Infectious agent that contains only DNA or RNA, but never both

Consists of:

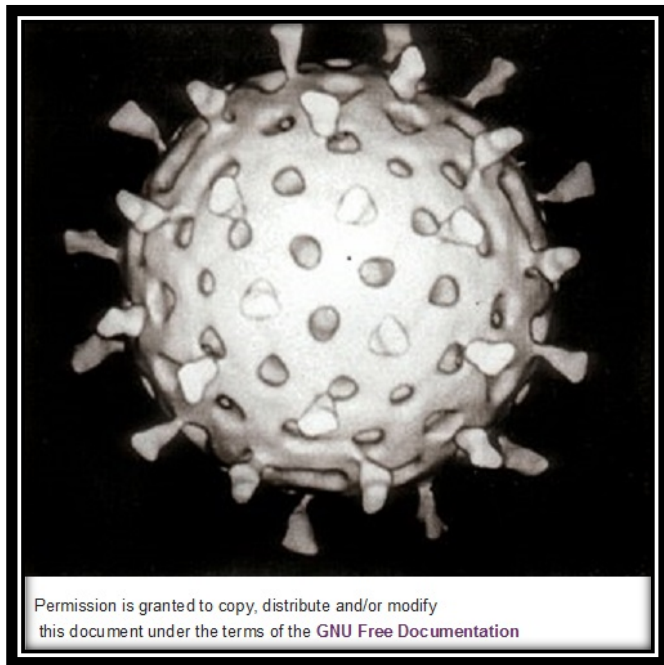
Capsid: protein coat

Nucleic Acid Core: DNA or RNA (called a **retrovirus**)

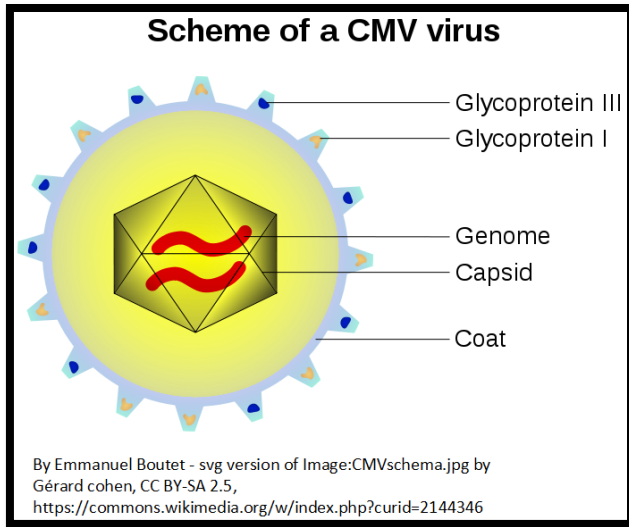
Sometimes a **membranous envelope**

Many shapes are possible:

Polyhedral, circular, filamentous



Chapter 11 - Biodiversity



★ Smaller than a ribosome!

Animals or plants can get a virus

Viruses that infect a bacteria are known as **bacteriophages** or phages for short

Viruses need a host to reproduce “obligate intracellular parasites” and possess a limited host range. For example, Virus X only infects your upper respiratory tract and not your GI tract!!

If virus enters the host cell and causes it to rupture (lysis)... cell death occurs. This is the **lytic cycle**. The phage is virulent! Lytic Cycle = Kiss of Death

If virus becomes incorporated in the host cell and allows replication of more viral particles without killing the host, we call it a **lysogenic cycle**.

★ A prophage is a bacteriophage that has become integrated into the bacterial chromosome

In other words: If in a lysogenic cycle, viral genome is incorporated without lysis, we say it has been incorporated as prophage.

As I pointed out, a virus can be DNA (herpes, small pox, cow pox) or RNA (HIV).

HIV is a retrovirus... an RNA virus that reproduces by transcribing its RNA into DNA using **reverse transcriptase** enzyme. ★ Reverse transcriptase is also called RNA-directed DNA polymerase.

I have several nice problems awaiting you in the DAT Destroyer book, which will challenge and interest you.

Other infectious particles include:

Viroids:

Circular RNA molecules devoid of a protein coat

Chapter 11 - Biodiversity

Smallest infectious pathogen known!

Seen in plants mostly >99%

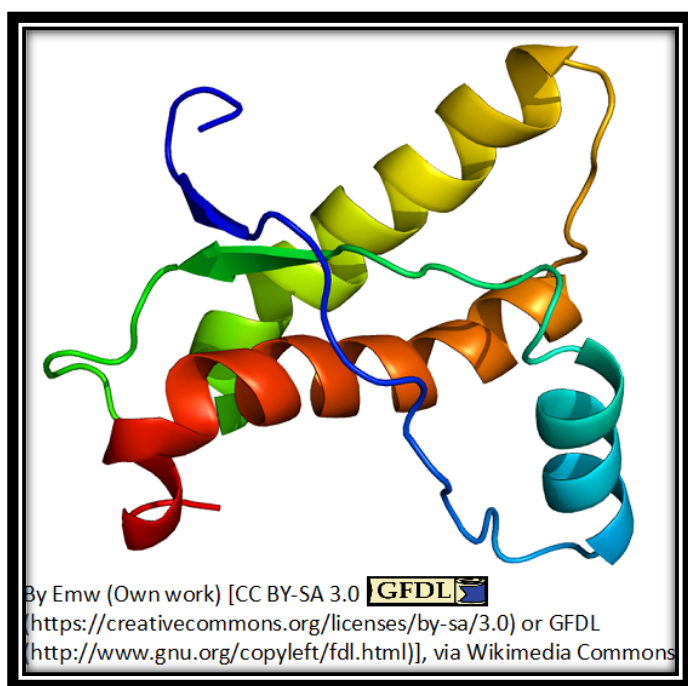
Only human disease known to be caused by a viroid is Hepatitis D.

Prions:

Infectious proteins that are involved with causing proteins to incorrectly fold.

e.g. Mad Cow Disease, Scrapie in sheep and goats, Kuru, and Creutzfeldt-Jakob Disease

These agents especially like to cause damage to proteins found in the brain.



Important Definitions for the DAT Exam

Obligate Anaerobe: killed by O_2

Obligate Aerobe: need O_2 to grow

Facultative Anaerobe: prefers O_2 if available, but could switch to fermentation if needed

★ **A great question awaits you in Destroyer. It is vital you do all my problems in that book.**

Photoautotroph: use light for photosynthesis. CO_2 is used to make organic molecules like sugar! Cyanobacteria, plants, and algae are here!! Purple non-sulfur bacteria, heliobacteria for example.

Chemoautotroph: seen in prokaryotes. CO_2 is the carbon source too, but an inorganic substance is an energy source. H_2S , NH_3 , or even Fe^{+2} are oxidized. No light needed!!

Chapter 11 - Biodiversity

Photoheterotroph: light is needed for ATP production, but gets their carbon from various organic sources like fatty acids or carbohydrates that other organisms produced.

Chemoheterotroph: Energy is obtained from organic compounds! Bacteria, Fungi, most Protists, animals are here!!

Bacteria can be decomposers along with fungi. These are the two main groups of decomposer-organisms

A **detritivore** is a classification of decomposers. Although not directly part of the decomposition process per se, they contribute to it. Decomposers like bacteria and fungi break down the component of an organism into simpler parts, the detritivores like worms, slugs, lice, eat away at the dead organism!

Chapter 12 - Fungi

Fungi



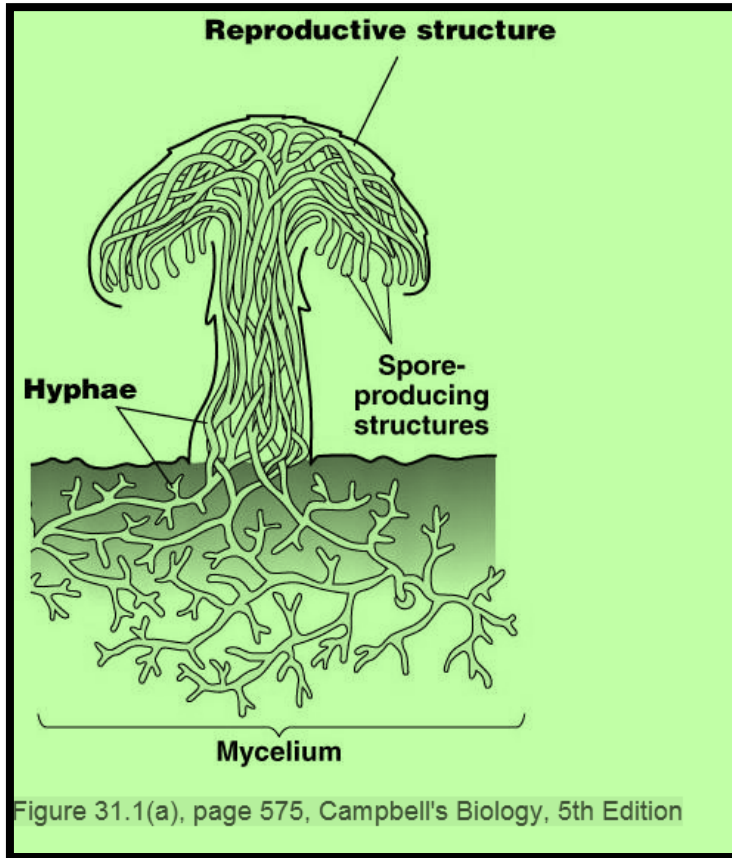
By Przykuta (Own work) [GFDL (<http://www.gnu.org/copyleft/fdl.html>), CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or CC BY-SA 2.5-2.0-1.0 (<https://creativecommons.org/licenses/by-sa/2.5-2.0-1.0>)], via Wikimedia Commons

Chapter 12 - Fungi

Are **eukaryotic heterotrophs**

They secrete digestive enzymes and then absorb the soluble products of digestion

Composed of filaments called **hyphae**; collectively the hyphae are called **mycelium**.



Can reproduce sexually or asexually

Haploid state predominates, but they do alternate between haploid and diploid stages

Saprophytic, they break down the remains of living organisms that have died

Immotile and have **cell walls...Energy is stored in the form of GLYCOGEN.**

A fungus not only attacks dead matter, but may attack living tissue such as seen in Athletes Foot

More similar to a human cell than a bacterial cell

Most are multi-celled

Some fungi are **parasites** (get nutrients from host tissue)

Some fungi are **saprobies** (get nutrients from nonliving organic matter such as dead animals, and waste of living organisms)

Chapter 12 - Fungi

★ All cases, they rely on extracellular digestion and absorption. ★ Fungi are needed for decomposition of organic material.

The study of fungi is called **Mycology**.

The cell wall of a fungi contains **chitin**. Chitin is a polysaccharide made up of amino sugars. Chitin is also found in the exoskeleton of arthropods.

Fungi include:

1. Mushrooms
2. Toadstools
3. Yeasts
4. Molds (i.e. *Rhizopus stolonifer*)
5. Mildew

★ A **lichen** is the mutualistic association of a fungus and cyanobacterium or a photosynthetic alga such as green algae.

Lichen often live on areas like bare rock and is seen in the Arctic Tundra where reindeer survive on them.

A fungus produces **spores!!**

Depending on conditions such as: dampness, food availability, and temperature: Sexual spores, asexual spores, or both!

Major groups: Ascomycetes “Sac Fungi”, Zygomycetes, Oomycetes (water molds)

★ **For the DAT, just know if you see “mycetes” you are dealing with a fungi!**

Chapter 12 - Fungi

Reproduction

Fungi are categorized mainly on the basis of their reproductive structures.

Bottom Line:

Asexual reproduction is done by spores. The spore is a haploid cell resulting from mitosis of a haploid parent. Water, wind, and other organisms can disperse the spores. When conditions are favorable, the spores develop into new hyphae.

Yeast do not make spores; they reproduce by a process called **budding**... in budding we see the offspring being “pinched” off from the parent.

Sexual reproduction is also done by all fungi. Mating between haploid hyphae occurs... resulting in a diploid spore called a Zygospore. This Zygospore can undergo a meiosis forming new haploid cells that can also develop new hyphae.

★ In the Zygospore we see a specialized hypha that bears a spore sac called a **sporangium**. These spores within this structure give rise to a new mycelium... hyphae grow from these mycelium.

Symbiosis

A fungal hyphae can also associate with a plant root and is called a **mycorrhizae**. The fungus helps the plant by absorbing needed minerals from the soil and passing them on to the plant.

Two examples of mutualism we have seen:

- A) Lichen: fungus and cyanobacterial (or green alga)
- B) Mycorrhizae: fungus and plant root

Fungi can help or harm man.

Some fungi ruin crops, some cause diseases such as invasive Candida infections, histoplasmosis, etc.

Drug Interaction and Chemical Structure

★ Antifungal drugs can be made that target the fungal cell wall. Fungal membranes can also be targeted, since they are different from our membranes. Thus, hopefully you can see that antibiotics used to treat a bacterial disease would not work against fungi and vice versa.

Athletes Foot, Jock itch, and yeast infections would be treated by an anti-fungal agent.

Remember:

Bacterial cell wall = peptidoglycan

Fungal cell wall = chitin

Their chemical structure is different, and I hopefully have driven this point home to you. This difference allows the drug designer to properly target the pathogen.

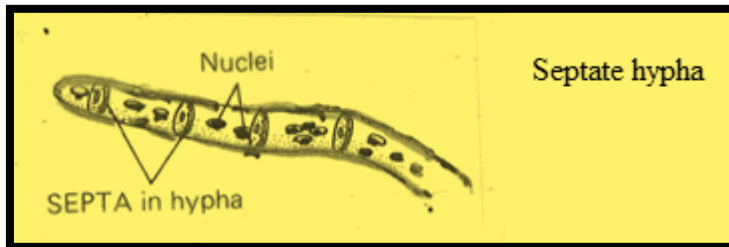
Chapter 12 - Fungi

Synctium & Coenocyte

Mitosis usually gives us two separate cells, each possessing its own nucleus, cytoplasm, and cell membrane. However, this does not always occur.

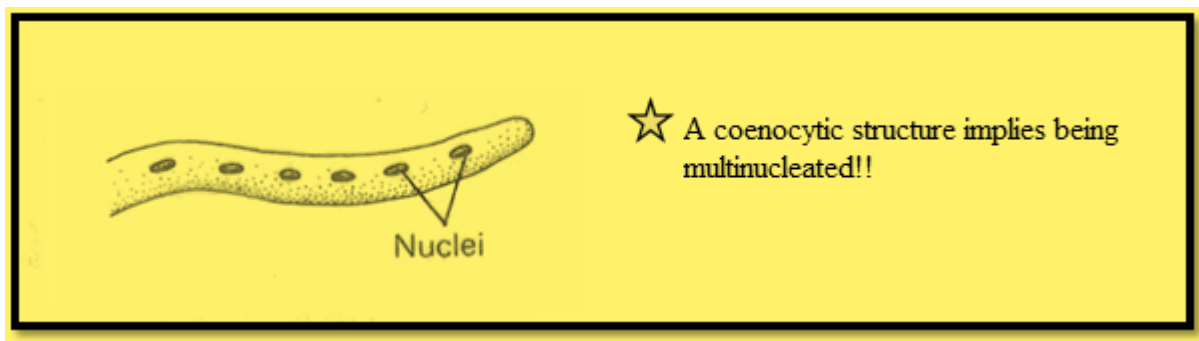
Sometimes, cell division does not do cytokinesis. The result is called a **synctium** in animals, or a **coenocyte** in plants.

Some hypha are coenocytic. Usually, hyphae are divided into cells by structures called septa shown below:



These septa have pores that allow organelles and nuclei flow from cell to cell. Some fungi lack septa and are called coenocytic fungi. Hundreds or thousands of nuclei are present. This was caused by repeated cell division of nuclei without cytokinesis.

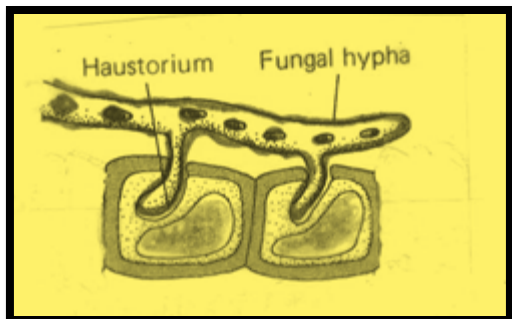
Coenocytic hypha:



What is a haustoria?

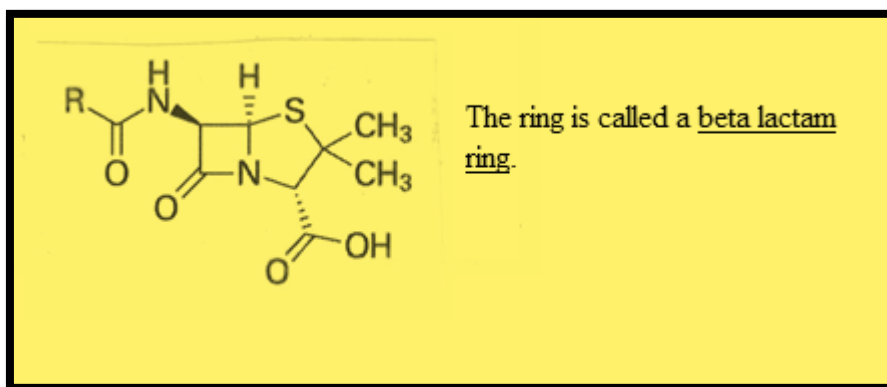
Parasitic fungi absorb nutrients from the body fluids of the host by using specialized hyphae called haustoria. The haustoria can penetrate the cell wall and lie against the cell membrane in order to absorb nutrients.

Chapter 12 - Fungi



Penicillin

Do you know what the below molecule is?



This is the structure of **penicillin**!

R can change. By changing the R group, we can derive Penicillin G, Penicillin V, Ampicillin, and many more!!

Discovered by Alexander Fleming, one of the world's most widely-used and effective antibiotics was penicillin. It is made by a fungus!! Penicillin interrupts bacterial cell wall synthesis.

Resistance to penicillin usually is a slow process. A major mechanism developed by bacteria is through the production of Beta-Lactamases which cleaves the beta-lactam ring!

Hopefully, you can see the huge importance of our fungi friends!

Chapter 13 - Protists

Protists

Eukaryotic organisms in domain Eukarya

Have a nucleus and other membrane bound organelles

This kingdom has both unicelled as well as multicelled organisms, but most are **unicellular**.

Include **photoautotrophs** and **heterotrophs**.

Heterotrophs are organisms unable to make their own organic compounds... they eat other organisms or feed on autotrophs.

Protists vary in function as well as in structure more than any other eukaryotic organism.

Protists include:

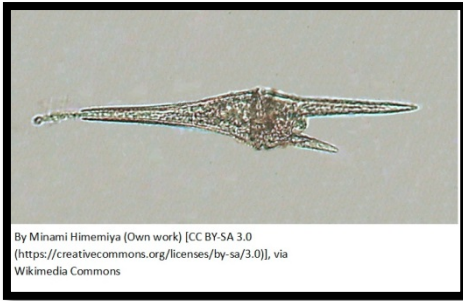
Euglena: (unicellular)



live in fresh water, move by flagella. If deprived of light it loses its chloroplast and becomes a heterotroph!! The chlorophyll pigments in their chloroplasts are similar to land plants and green algae.

Chapter 13 - Protists

Dinoflagellates: (unicellular)



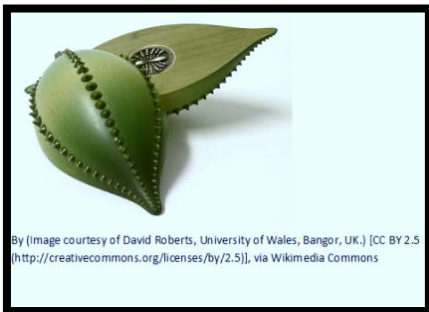
Most are photosynthetic members of marine plankton... single celled.

Depending on their pigment color... they appear red, brown, yellow, green, etc.

Certain blooms can be toxic to marine life

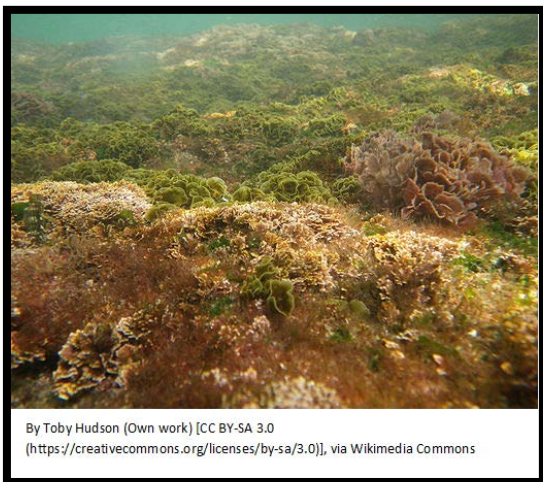
Certain species cause a red tide to occur where we see an enormous “bloom” or growth rate.

Diatoms:



Unicellular algae with a glass-like appearance consisting of SiO_2 wall structure. Over 5,000 species exist!

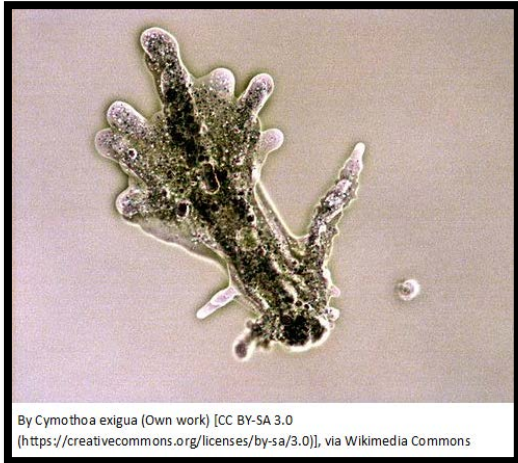
Algae: (may be unicellular, colonial, or multicellular)



Chapter 13 - Protists

Golden (chrysophyta), brown (kelp) (phaeophyte), green (chlorophyta), red (rhodophyta)

Amoeba: (unicellular)

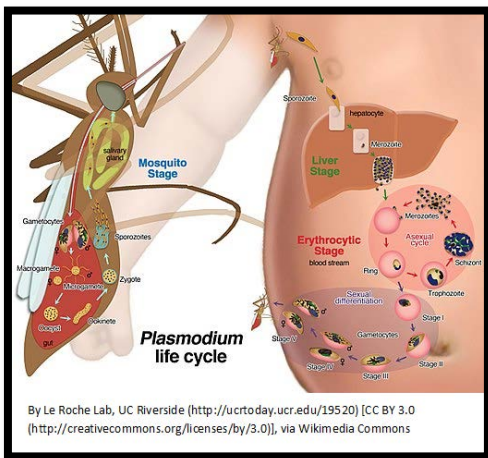


Move by pseudopodia or “false feet”

Freshwater

Most feed on bacteria, algae, and even some protozoans

Plasmodium: (unicellular)

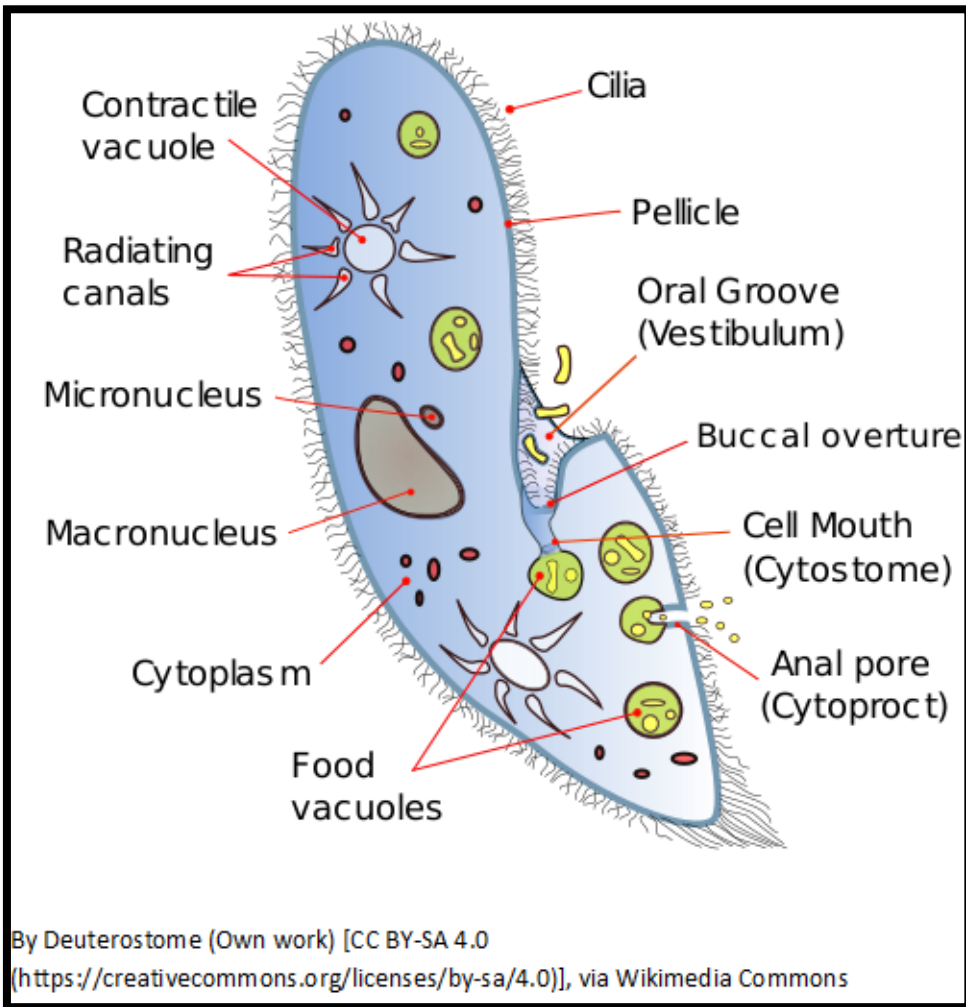


This causes Malaria

A type of sporozoan... bad news!

Chapter 13 - Protists

Paramecium: (unicellular)



★ Make sure you are clear that the contractile vacuule acts as a water pump.

Chapter 13 - Protists

Are ciliates

Use cilia for swimming

Freshwater and marine habitats

Have a contractile vacuole used to expel water

They are built for speed!!

Slime Molds: (unicellular)



Free-living and quite predatory... they creep around like animals and engulf food... they love to eat on bacteria!

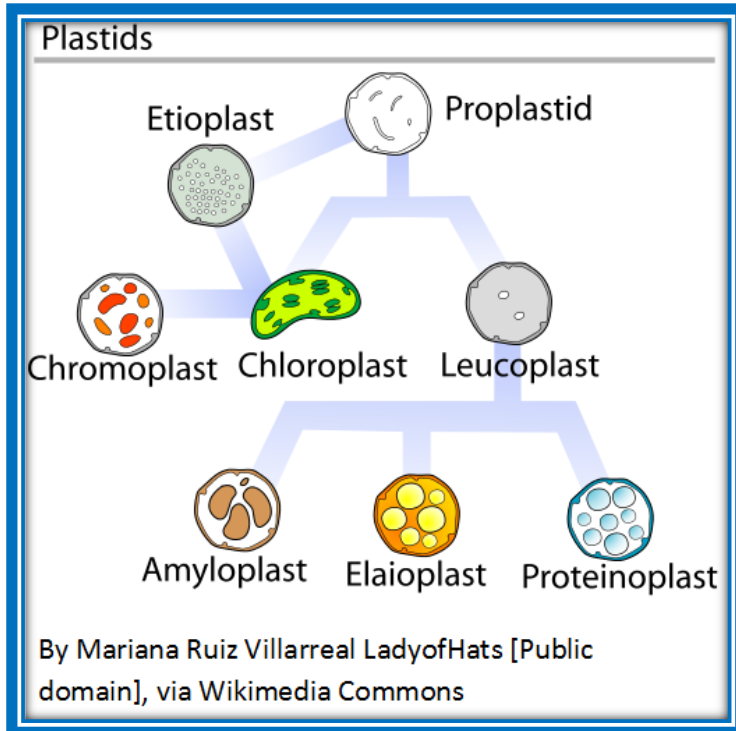
★ An interesting side note about Malaria-

Heterozygotes for the sickle cell gene are less likely to get Malaria. The organism (plasmodium) spends much time in the red blood cell (which live for about 120 days) ... the sickle cell has a shorter life-span and prevents the plasmodium from completing its life cycle. This is indeed a “selective advantage” to individuals living in areas such as Africa where Malaria is a major cause of death.

★ Mitochondria and chloroplasts are **endosymbionts**. Both of them might have been smaller prokaryotes that began living within larger cells! Mitochondria and chloroplast have their own DNA!!

Plastid: one family of closely related organelles that include chloroplasts and chromoplasts

Chapter 13 - Protists



Mitochondria and chloroplasts do indeed resemble bacteria. The mitochondrial code even has a few unique codons that do not occur in the “normal” genetic code of living cells!!

Protists contain the most diverse mitochondria genomes, having five different types. Animal cells have only one.

Interestingly, DNA in a mitochondrion is circular, like a bacteria and mitochondria multiply by “pinching” in half, just like a bacterium. In addition, mitochondria have their own cell membranes, just like a bacterium.

The endosymbiont event must have occurred early in the history of the eukaryote... all eukaryotes have them!!

★ Hydra: are NOT protists, but small aquatic animals, they are multicelled. They are in the animal kingdom. I listed it here for you, however!

Freshwater organisms of the phylum Cnidaria. They have the ability to regenerate and do not appear to die of old age!! They have tentacles with stinging cells called **nematocysts**. They reproduce most often by the asexual process of budding. They are usually non-motile (sessile).

Chapter 14 - DNA and RNA... Nucleic Acids

DNA and RNA... Nucleic Acids

In the nuclei of cells, we find the **chromosomes** that contain the hereditary instructions for the synthesis of over 250,000 proteins unique to man.

All cells except ova and sperm contain 23 pairs of chromosomes, for a total of 46 in man.

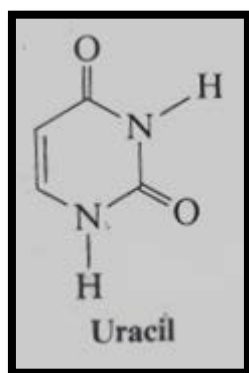
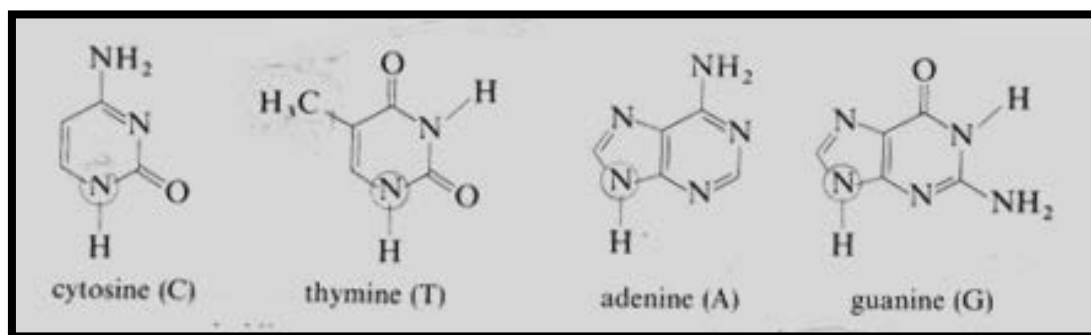
Chromosomes contain large numbers of **genes** which represent the **fundamental heredity unit**.

At the molecular level, growth and reproduction of organisms are directed and carried out by DNA and RNA... the nucleic acids.

Voluminous books are written on DNA and RNA, but **for your DAT exam, we need to only touch the basics**. Details are provided in Biochemistry text books such as Stryer, Leninger, and Campbell. We need not concern ourselves with huge details... **just the essentials for the DAT**.

A nucleic acid is a **polymer** made from monomeric units called **nucleotides**. I will present them shortly.

DNA: contains the N-bases adenine, thymine, guanine, and cytosine pictured below:



RNA: contains the N-bases adenine, guanine, cytosine, and **uracil**, no thymine.

Purines: include A and G ... 2 rings!!

Pyrimidines: include C, U, T... 1 ring!!

Chapter 14 - DNA and RNA... Nucleic Acids

(Easy way to remember this... think pie... (py). Before you eat a “py” you cut it... and you only eat one piece... thus one ring).

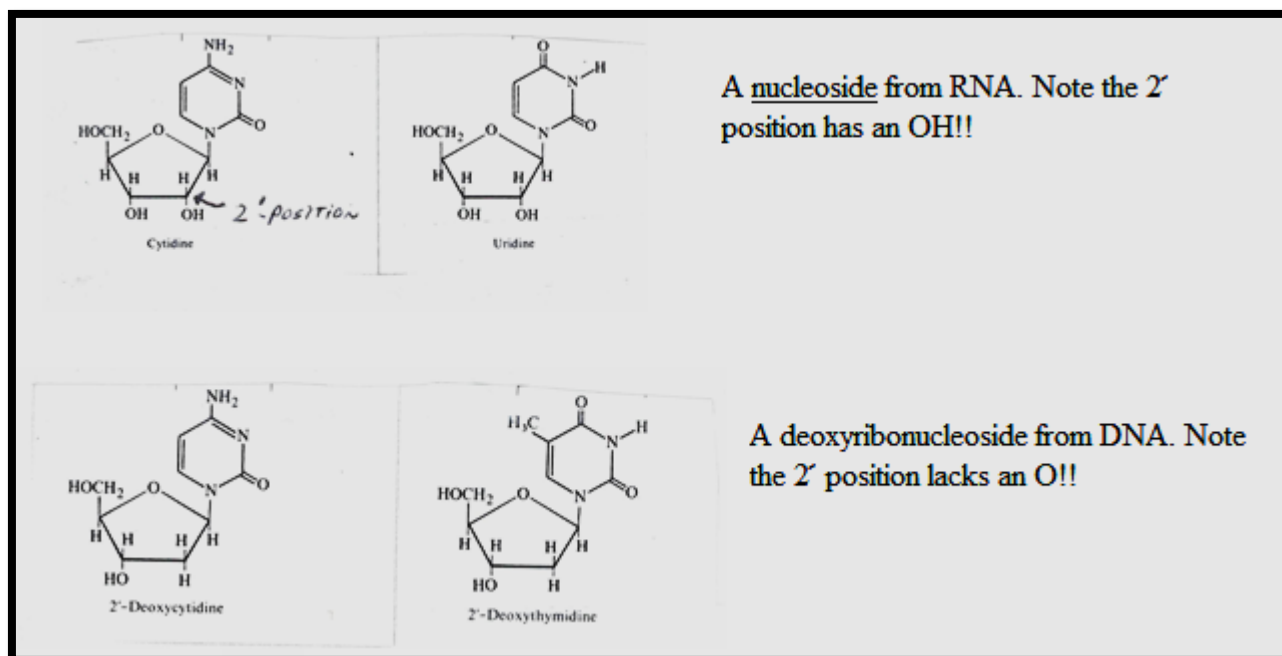
The DNA of all species is based on the sequences of A, T, C, and G. All species use these four nucleotides. This is a very important point to remember!

A few points to understand:

A **nucleotide** = sugar, phosphate, and N-base

A **nucleoside** = sugar and base

DNA has one less O at the 2' position; the sugar is 2'-deoxyribose, while in RNA we have ribose. See below:



Don't memorize anything... just understand the concept.

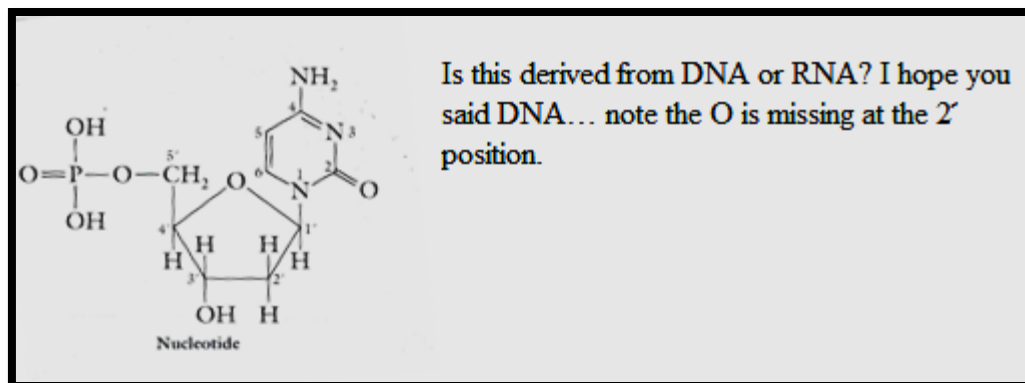
Let us now examine a nucleotide.

Sugar in DNA... deoxyribose

Sugar in RNA... Ribose

5 carbon sugar = furanose ring!

Chapter 14 - DNA and RNA... Nucleic Acids



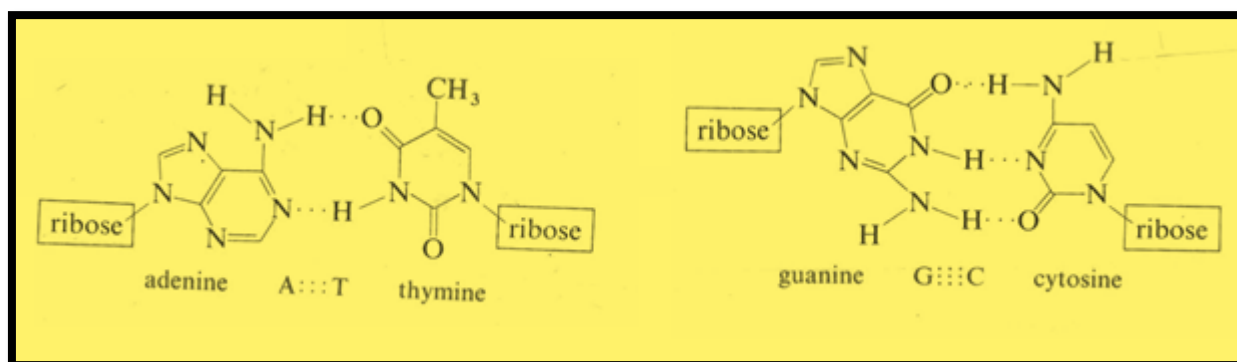
DNA

DNA will form a helix structure... note the sugar and phosphate makes up the backbone, and holding the two strands together are hydrogen bonds. Rosalind Franklin produced a “photograph” of this remarkable molecule that paved the way for Watson and Crick to deduce its **double-helix structure**.

You will notice that the following pairings exist:

A = T two hydrogen bonds

C ≡ G three hydrogen bonds



According to the **rule of Chargaff**:

Amount of adenine = amount of thymine

Amount of cytosine = amount of guanine

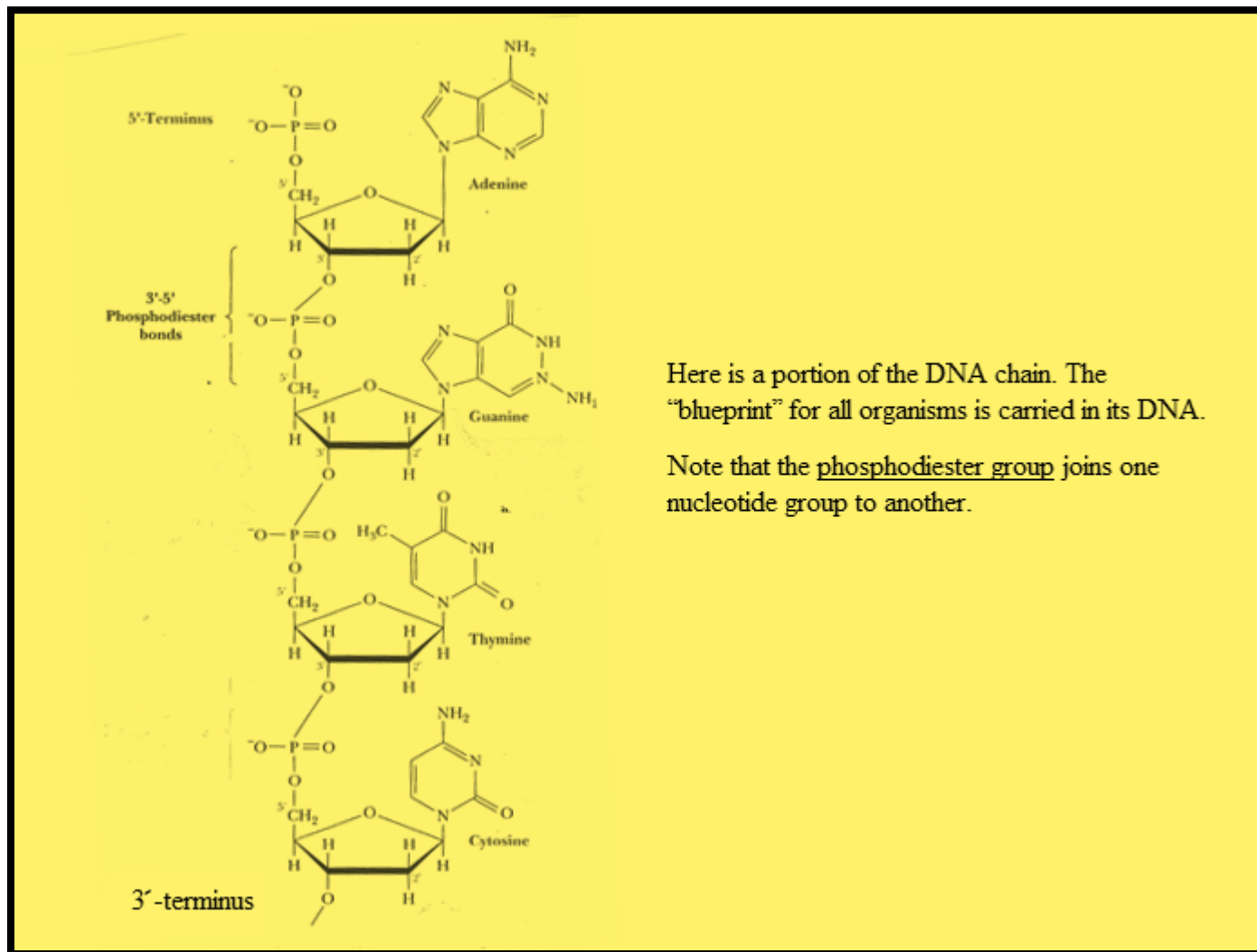
★ The hydrogen bonds and hydrophobic interactions between the stacked bases inside the helix stabilize the helical structure.

★ A purine pairs with a pyrimidine always!! i.e. A = T, C ≡ G

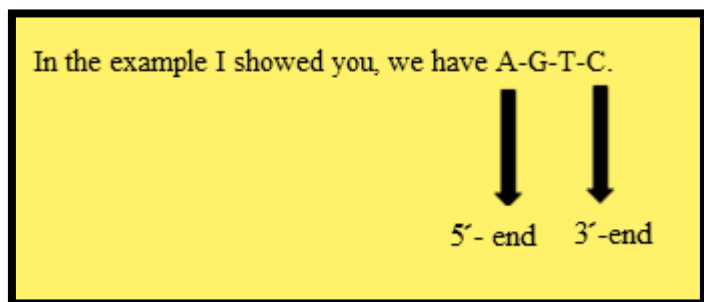
Why?

Chapter 14 - DNA and RNA... Nucleic Acids

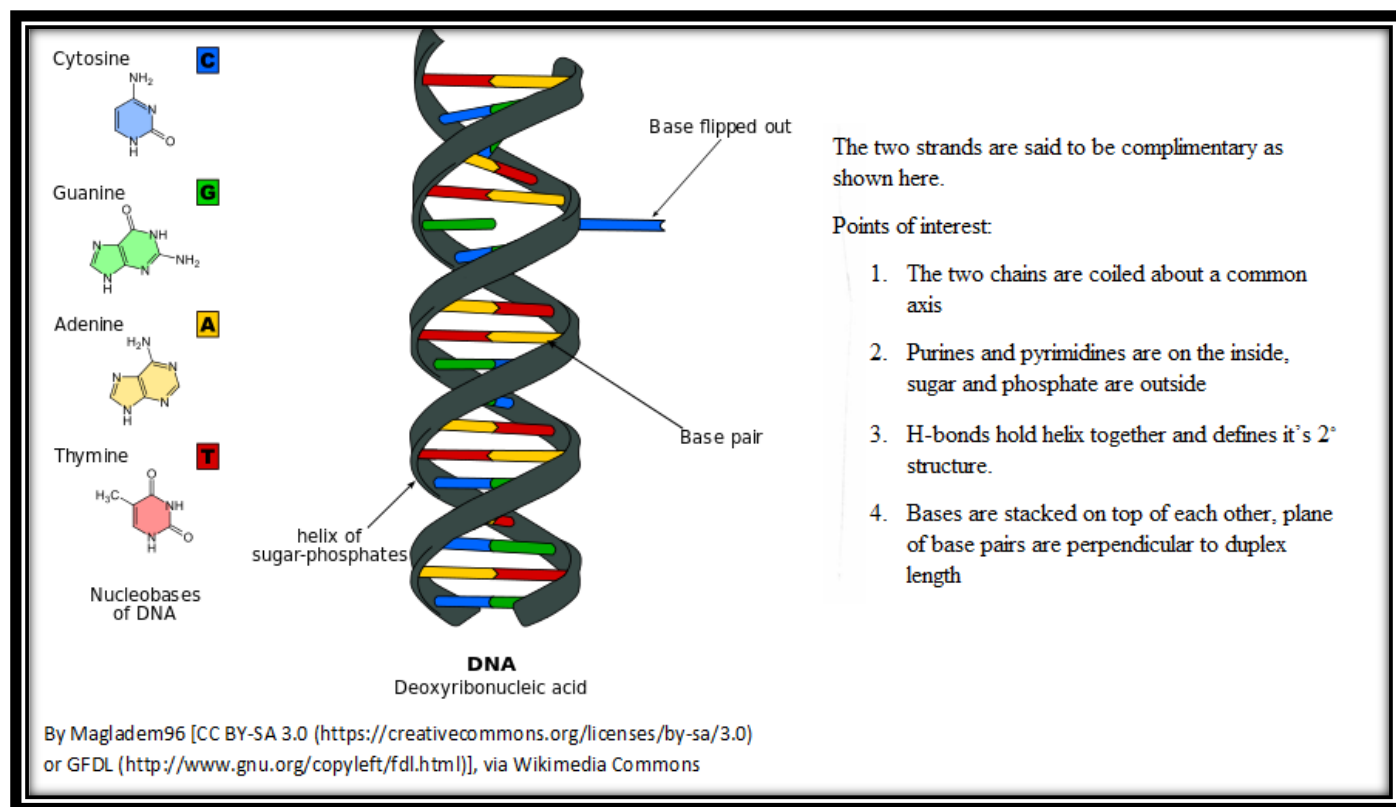
There is a limited amount of space in the helix. This space just accommodates a purine and a pyrimidine. The space is not sufficient for two purines, and is too large for two pyrimidines. Hydrogen bond formation is critical for the stabilization of the helix. Having a purine pair with a pyrimidine would allow for the most efficient hydrogen bond formation.



By convention, the bases located along this backbone are written in 5' to 3' direction.



Chapter 14 - DNA and RNA... Nucleic Acids



★ As we increase the % of GC we increase stability and melting point, since more hydrogen bonds are in GC than AT!! A = T regions will be the first to melt and break!!

DNA molecules vary greatly in length from one specie to another.

DNA is also found in bacteria and viruses!

Problems

How does the following factors influence the behavior of a double-stranded DNA molecule?

A) Length of DNA vs. Melting Temperature, T_m

The stability of a DNA duplex is dependent on the hydrogen bonds between A and T and between G and C. Since the number of such hydrogen bonds increase with the length of the DNA, the T_m increases with the length.

B) As the amount of NaCl decreases, the melting temperature decreases.

The DNA duplex is highly negatively charged. The negative charges on phosphodiester linkages will normally repel each other. This weakens the interaction between the two strands. In the presence of NaCl the positive Na^+ cation shields the negatively charged phosphate esters. This increases the stability of the helix. Therefore, as the NaCl concentration decreases the amount of shielding decreases and the stability of the helix decreases. This results in a lower T_m .

Chapter 14 - DNA and RNA... Nucleic Acids

- C) Renaturation of single strands to form double strands occurs more rapidly when the DNA concentration is increased.
The renaturation of the double helix requires that complementary sequences find each other. This is a bimolecular interaction and therefore the rate increases with the concentration of the DNA chains.
- D) The T_m is reduced when urea is added to the solution.
Urea is a polar molecule which can act as an H-bond donor and an H-bond acceptor. It therefore interferes with H-bonding. Since H-bonding interactions are in part responsible for stabilizing the double helix, urea lowers the T_m by decreasing the H-bond interactions.

These 4 above problems do indeed make you think.

Let's do a few more theory questions:

Problem #1:

If a DNA sample has 20% cytosine, what is the % of adenine.

Answer:

Recall, C pairs with G. 20% C means 20% G too, this makes 40%. The 60% left over must be equally split between A and T. Thus 30% T and 30% A.

Problem #2:

Discuss the water solubility of: the phosphate group, ribosyl group, and the nitrogen bases (purines and pyrimidines).

Answer:

Ribosyl group (polar) and phosphate group (negative charge) will be hydrophilic... they are located outside our helix and are water soluble.

Purines and pyrimidines are relatively insoluble in water (hydrophobic), consistent with their location in the helix interior.

Problem #3:

What biology or histology technique is used to identify chromosomal material or DNA?

Answer:

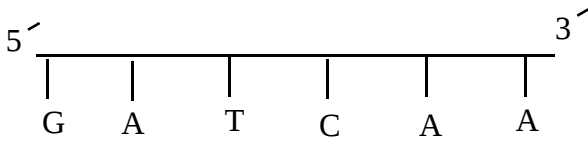
We use the Feulgen stain. DNA stains reddish in color. Mild acid hydrolysis cleaves the molecule and a reaction reveals this red color. Details of the reaction need not concern us here.

Problem #4:

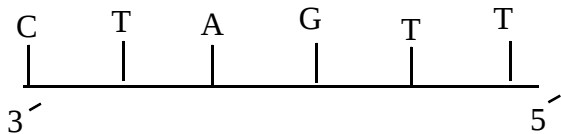
Write the complementary sequence for:

Chapter 14 - DNA and RNA... Nucleic Acids

DNA



Answer



★ Strands are anti-parallel.

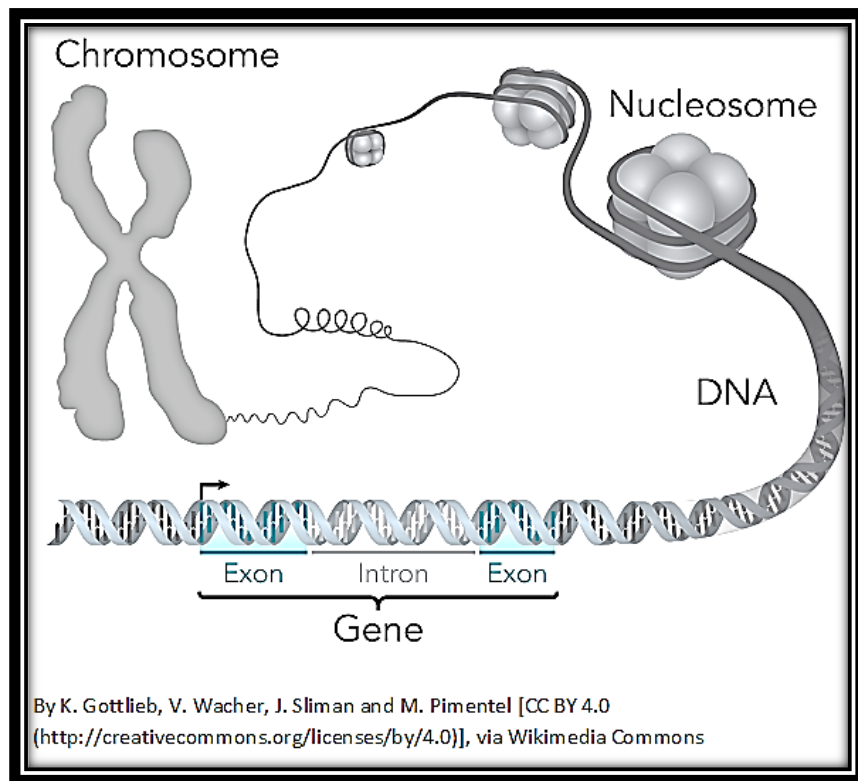
DNA is an enormously big macromolecule and must be compacted to fit into the nucleus. (Total DNA = genome).

DNA is wrapped around proteins called **histones** which look like a bead with a string wrapped with it. This entire complex, DNA and histone = **nucleosome**.

Nucleosomes are the basic unit of DNA packaging.

Chapter 14 - DNA and RNA... Nucleic Acids

Histones are rich in + charged amino acids lysine and arginine and this allows tight binding to the negatively charged DNA.



Chapter 14 - DNA and RNA... Nucleic Acids

Euchromatin and Heterochromatin

The nuclear DNA is found in different configurations. We have:

- A) Euchromatin
- B) Heterochromatin

Heterochromatin

Dark staining in electron micrographs

★ DNA is not actively transcribed

Located mainly near nuclear envelope

Compacted

Eukaryotic

Euchromatin

★ Eukaryotic, DNA is available for transcription

“True chromatin”

More dispersed and less compacted.



Black area = heterochromatin

White area = euchromatin

As you can see, the chromosome is a dynamic structure that is condensed, not condensed, modified, and changed as needed for the metabolic (gene) activity of the cell including mitosis and meiosis.

Chapter 14 - DNA and RNA... Nucleic Acids

Experiments

A few experiments you need for the DAT exam: I will keep this simple!

The famous **Hershey-Chase experiment** concluded that DNA and not protein is the actual genetic info!

In this experiment the fate of radioactive sulfur and phosphorus was studied. Radioactive sulfur labelled the proteins, radioactive phosphorus labeled the DNA. They noted which of these molecules entered the bacterial cell. Bacteriophages (viruses) were used.

Result: Phage DNA entered the bacteria, phage protein did not.

Fred-Griffith Transformation Experiment

Dr. Griffith had two strains of bacteria:

A: Pathogenic (disease causing)

B: Nonpathogenic (harmless)

When he killed A (pathogenic) with heat and mixed the cell remains with living B, nonpathogenic bacteria, some of these harmless bacteria became pathogenic!! All further progeny were pathogenic!!

Clearly, this indicated that “something” from these dead bacteria has allowed these nonpathogenic bacteria to “transform”. This “something” was the DNA!!

The **Avery-McCarty-Macleod Experiment** in 1944 confirmed the work done by Fred Griffith to establish that DNA is indeed the genetic material.

Mitochondria and chloroplasts also contain their own DNA.

Radiation can damage DNA and result in cell death. Strands can break, bases can be modified, and structural damage can occur. Free radicals (i.e. $H\dot{O}\cdot$ with one unpaired electron) also can damage DNA.

When a cell undergoes apoptosis (programmed cell death), DNA fragmentation occurs.

RNA

Let us examine RNA...

Found as **single-stranded**

Contains A, U, C, G

Ribose sugar (not deoxyribose which lacks 2' OH)

3 major kinds:

Ribosomal RNA: provides physical makeup of the ribosome

Chapter 14 - DNA and RNA... Nucleic Acids

Messenger RNA: carries DNA info to ribosomes

Transfer RNA: transports amino acids to ribosomes

Cells contain up to 8x more RNA than DNA.

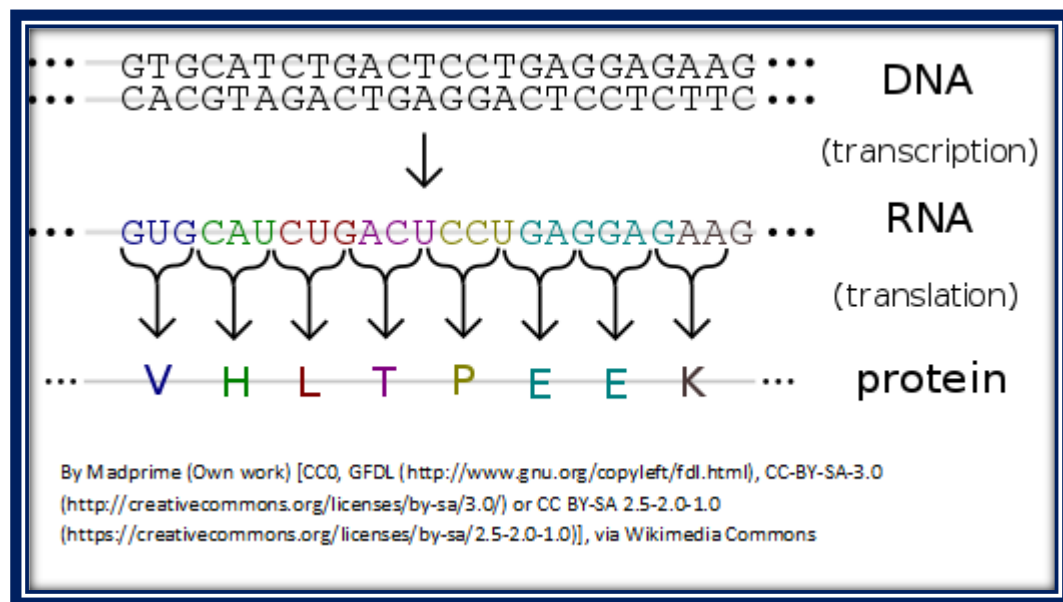
Ribosomal RNA: most abundant... Ribosomes are 60% RNA and 40% protein

T-RNA: lowest molecular weight, smallest

M-RNA: shortest lived

DNA $\longrightarrow$ RNA in a process called transcription... occurs in the nucleus.

If DNA is



Be careful on the DAT exam with this 3' -5' business!!

A few final problems for you:

Problem #1:

- A) Why does alkaline conditions partially denature (i.e. unwinds DNA in certain areas) the helix?
- B) Would the regions that unwind be richer in A = T or C $\equiv$ G? Why?

Answer:

By increasing the pH (i.e. making it more alkaline), we ionize some of the nucleic acid bases, and all of the phosphate groups, thus increasing the # of negatively charged groups, which promote unwinding of the helix to reduce charge repulsion!!

Chapter 14 - DNA and RNA... Nucleic Acids

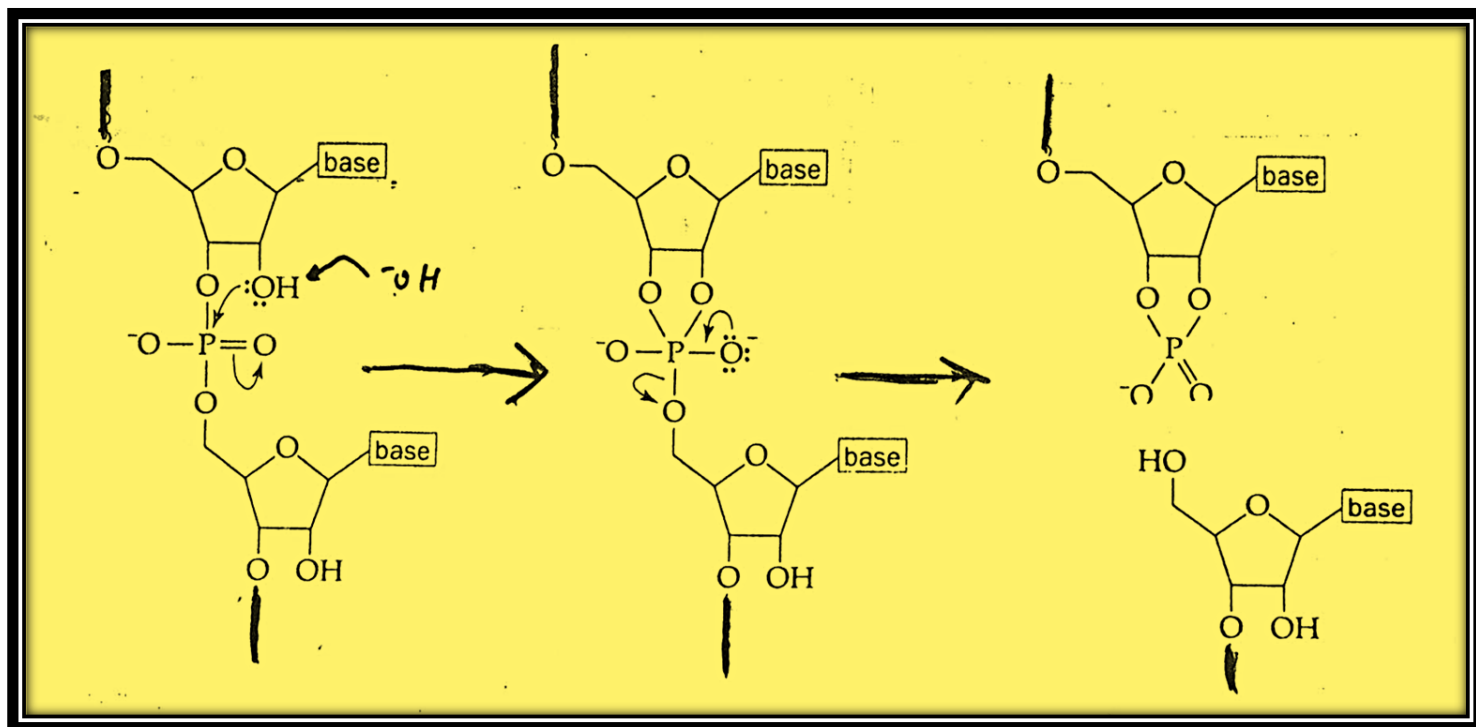
Between $A = T$ and $C \equiv G$ the H-bonds help to “counter” the unwinding, but since $C \equiv G$ has three H-bonds it will be stronger than $A = T$ since it only has two H-bonds, thus a region richer in $C \equiv G$ would unwind to a lesser extent. The area that unwinds clearly has more $A = T$ content.

Problem #2:

Which is more sensitive to base... DNA or RNA? Why?

Answer:

RNA has a 2' OH group if you recall. This 2' OH can launch an intramolecular attack as shown:



Chapter 14 - DNA and RNA... Nucleic Acids

Problem #3:

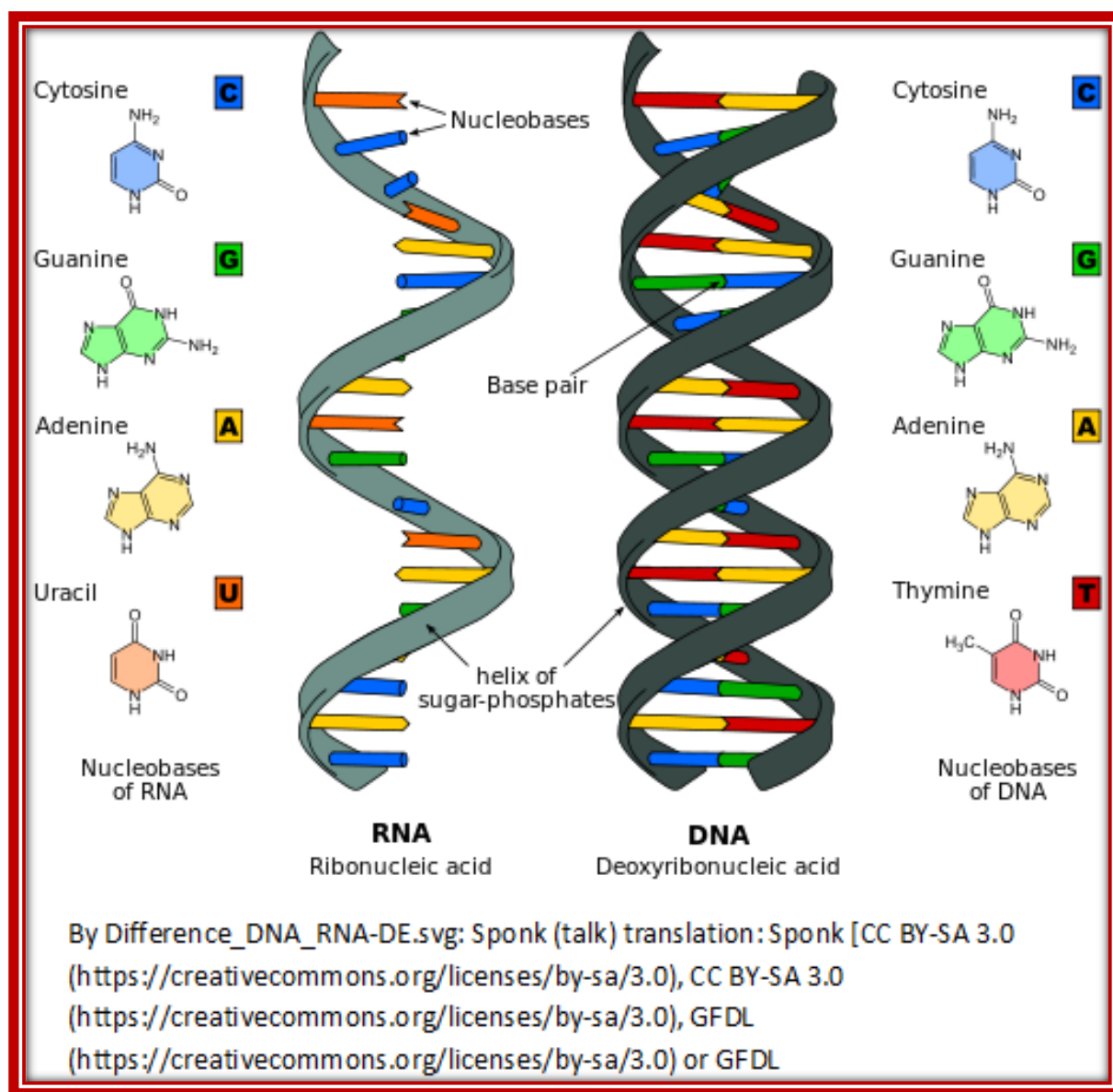
When DNA from *E. coli* is heated, it reversibly melts at about 72°C whereas when DNA from the bacterium *Pseudomonas aeruginosa* is heated it reversibly melts at 79°C. Explain.

Answer:

The *Pseudomonas* DNA must have more G ≡ C content since it has three H-bonds which stabilize the helix, thus higher T_m .

Finally, I hope you can see by now that DNA is indeed the “master” molecule. Next, we need to see how it replicates and how it moves through the nuclear membrane to the cytosol.

In our next section, we will examine the basics of replication, transcription, and translation.



Chapter 15 - DNA Replication

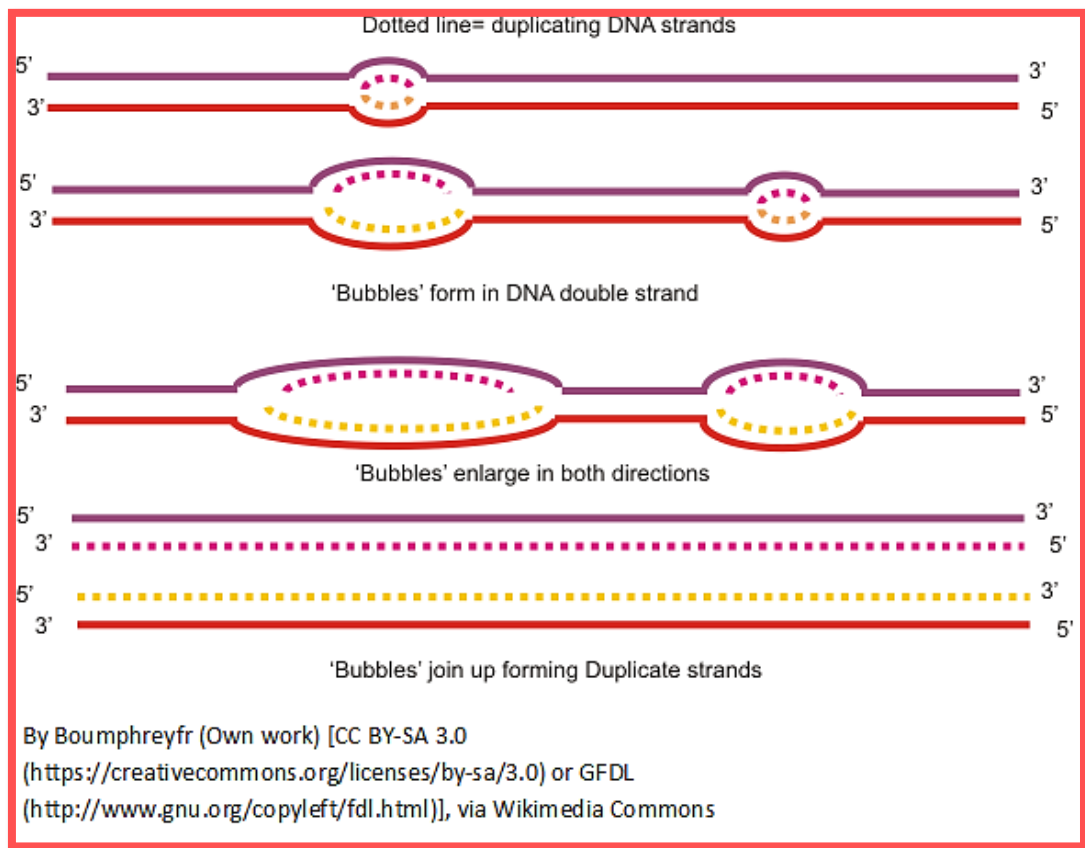
DNA Replication

Replication is an extremely complex process that needs about 25 different enzymes. Studies are still being done. I will present to you the essentials and try to make simplicity out of a process that is highly involved. Several YouTube videos under three minutes have been developed, and I urge you to look at them. They have done a great job.

Cell division in a human cell takes less than a day; DNA replication accounts for about a third of that time. Replication is carried out with an error level of one wrong nucleotide per 10 billion! This is vital to guarantee the preservation and integrity of the genome from one generation to another.

Replication of DNA begins at sites called **replication origins**... which are short DNA regions that have specific nucleotide sequences.

★ Eukaryotes have **multiple** origins of replication. Prokaryotes have a **single** origin.



Replication fork = Y-shaped region shown above is where parental DNA strands are being unwound.

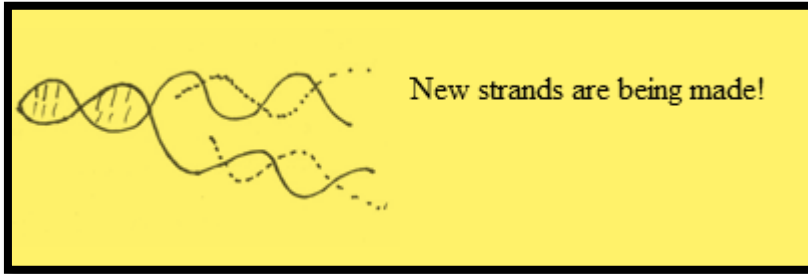
Thousands of bubbles in Eukaryotes, Prokaryotes a single bubble!

This is called a **semi-conservative** mechanism. Why?

The replicated DNA is $\frac{1}{2}$ new and $\frac{1}{2}$ old (i.e. $\frac{1}{2}$ parental, $\frac{1}{2}$ daughter).

Chapter 15 - DNA Replication

Many proteins help the DNA to unwind, in addition to enzymes called helicases. These enzymes will untwist the helix at the replication forks to allow them to be available as template strands!



★ The unpaired DNA strands are stabilized by “single-strand” binding proteins.

Topoisomerases: help to relieve strain in the double helix... as the double helix untwisted, it caused a tighter twisting and some additional strain ahead of replication fork.

The bottom line is this: as the DNA helix opens helicases, single-stranded binding proteins, and topoisomerases ensure that it will unravel in a coordinated and stabilized unit.

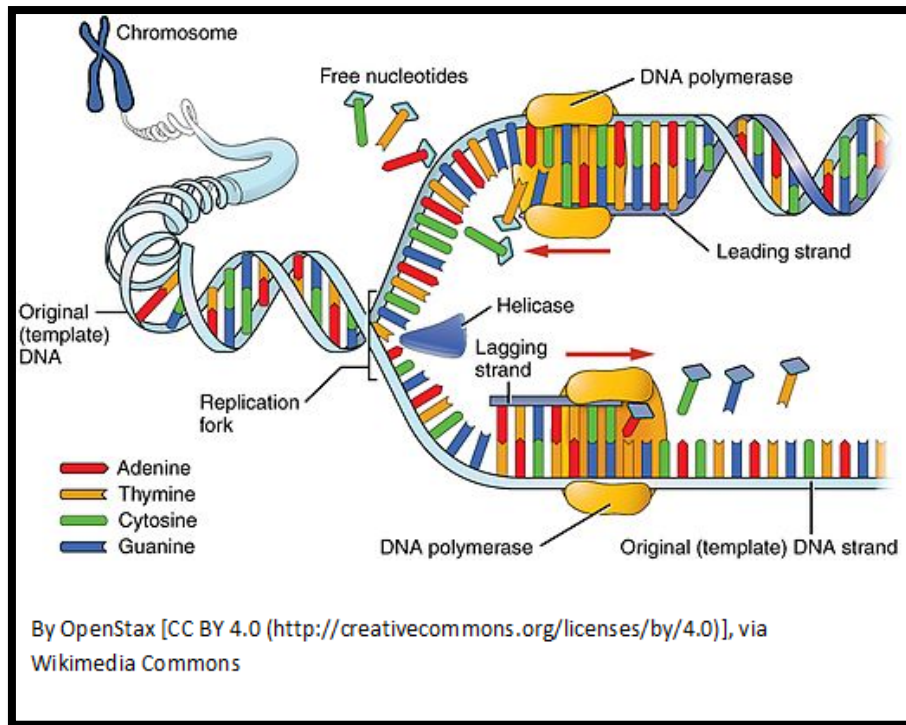
Now what? The unwound parental DNA strands are now able to serve as templates for the new complimentary strands.

★ The initial nucleotide chain is actually a small RNA stretch, not DNA. This is what is called an **RNA primer** and uses the enzyme primase. This enzyme starts an RNA chain using the parental DNA strand as a template.

The primer is about 5-10 nucleotides long, and base pairs with the DNA.

Chapter 15 - DNA Replication

A picture is worth a thousand words...



DNA polymerases can now catalyze the synthesis of new DNA by adding nucleotides to a preexisting chain, one by one... working in a 5' to 3' direction. T matches with A, and G matches with C.

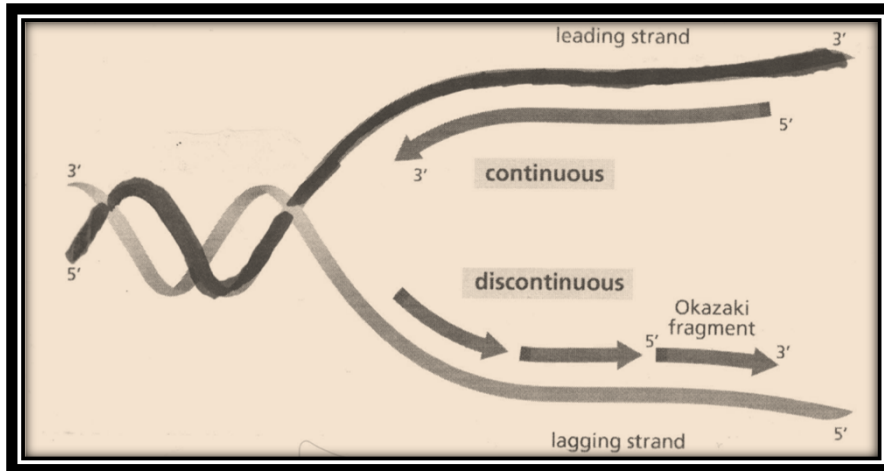
Here is the tricky part... the two DNA strands are not the same but run in opposite directions. They are said to be **antiparallel**.

The two strands are replicated differently; however both are elongated in the 5' to 3' direction. One strand is made in a **continuous fashion** and is called the **leading strand**, while the other strand is made in a **discontinuous fashion** and is called the **lagging strand**.

The leading strand is made continuously in 5' to 3' direction under the action of DNA Polymerase III.

The lagging strand, which is discontinuous, is made in a series of segments... which are called **Okazaki fragments**.

Chapter 15 - DNA Replication



★ Leading strand... no problem... but now the lagging strand must grow in the 3' to 5' direction. This is only possible if assembled in short 'segments' called Okazaki fragments.

One primer needed for leading strand if you recall...

Separate primers needed for each Okazaki fragment.

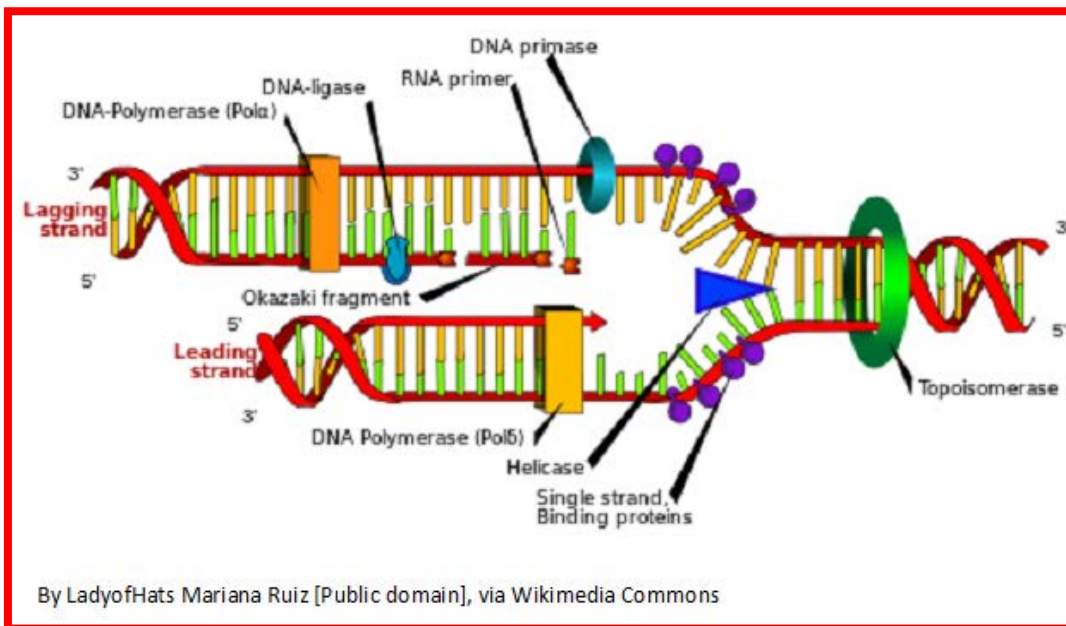
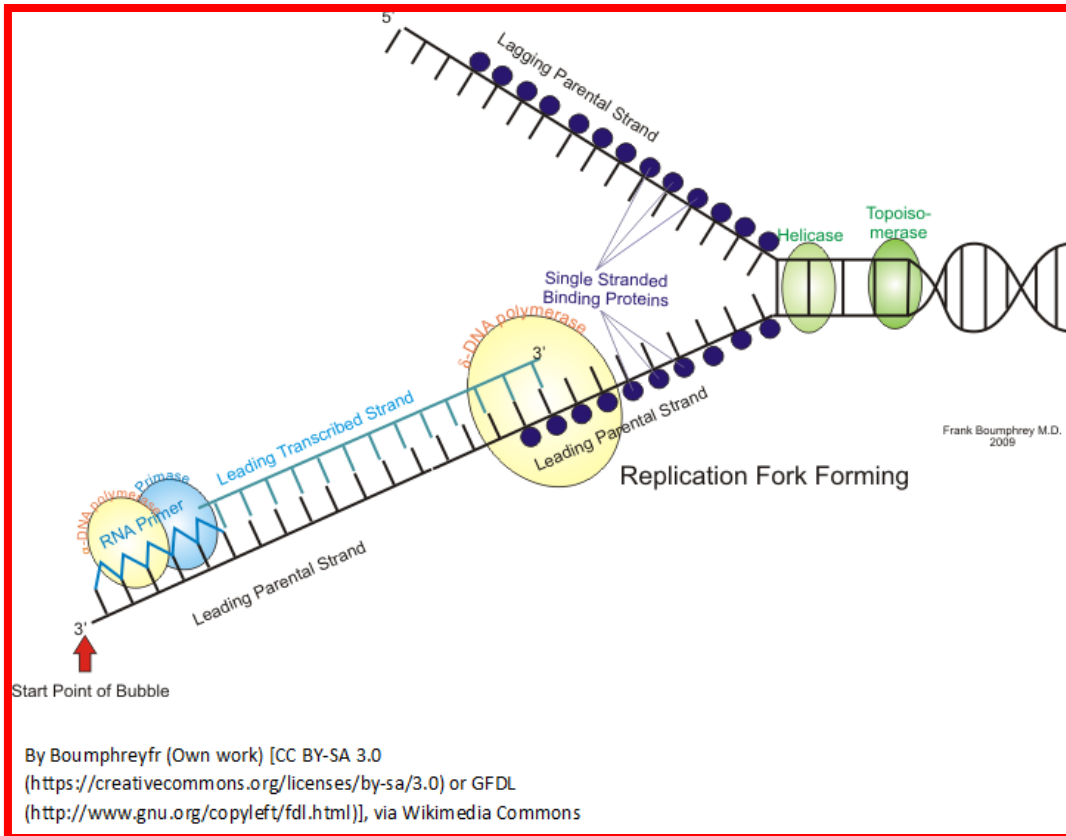
Two different mechanisms are at work: a) for leading strand and b) for lagging strand

Primers are removed and replaced with the correct DNA sequences in both mechanisms.

DNA Polymerase I removed the RNA nucleotides of the primer, and replaces them individually at the 3' end of the adjacent Okazaki fragment.

Okazaki fragments are joined into a continuous span under the direction of **DNA ligase**, to complete the lagging strand.

Chapter 15 - DNA Replication



The YouTube videos will really drive this home. This highly complex process will be more understandable after you watch the videos, re-do these notes!

Chapter 15 - DNA Replication

After each DNA replication, there is some nucleotide loss at the chromosome ends. The actual “tip” of the chromosome is lost. Eukaryotes have special nucleotide sequences called **telomeres** at their ends.

Telomeres:

Have no genes

Multiple repetitions of a short nucleotide sequence

A piece is lost during each cell division, and when only a small “nub” is left we see the end of cell division and cell death occurs.

Telomeric DNA protects the genes!!

★ In eukaryotic germ cells (egg and sperm) an enzyme called a **telomerase** is present. This enzyme catalyzes the lengthening of the telomeres and restores them to their original length (this enzyme is normally absent or very low in body cells!!). Thankfully for this enzyme, if not... we would be in big trouble. Why?

If we shorten germ cell chromosomes, essential genes would eventually be lost from the egg and sperm cell which would result in a disaster. Telomerase is a reverse transcriptase enzyme that carries its own RNA.

★ I have seen studies that have shown about 90% of human cancer cells show high levels of telomerase activity.... Thus, partially explaining why a cancer cell, as long as it has the needed nutrients and oxygen is immortal. Cancer cells escape cell death due to chromosomal shortening like most body (somatic) cells!! Cancer cells need a blood supply and needed nutrients.

Cells that experience severe hypoxia (low oxygen in tissues) may be induced to enter apoptosis or die by other mechanisms. Large areas of dead cells are called a **necrosis**. If a tumor manages to get enough blood and nutrients it can acquire a network of blood vessels... and have plenty of nutrients and O₂ to grow.

What was accomplished in all this?

DNA has now undergone a replication in a **semi-conserved manner**. Through this process, a single parent DNA is transformed into two daughter DNA duplexes, each containing one old and one new strand.

Chapter 16 - Transcription

Transcription



We make RNA using DNA as a template.

Occurs in the **nucleus** of eukaryotic cells... pre-RNA is made which then undergoes a modification to yield the final mRNA.

In prokaryotes, no processing or modification is done... mRNA directly forms.

Transcription proceeds under the control of **RNA polymerase**... this enzyme will separate the two DNA strands and nucleotides are joined together as they base-pair along the DNA template strand. Unlike DNA polymerase, no primer is needed... thus chain can start from scratch.

RNA polymerases bind to an area called the **promoter**. The promoter is simply where this enzyme attaches and initiates transcription.

Eukaryotes have at least three types of RNA polymerases, prokaryotes have one.

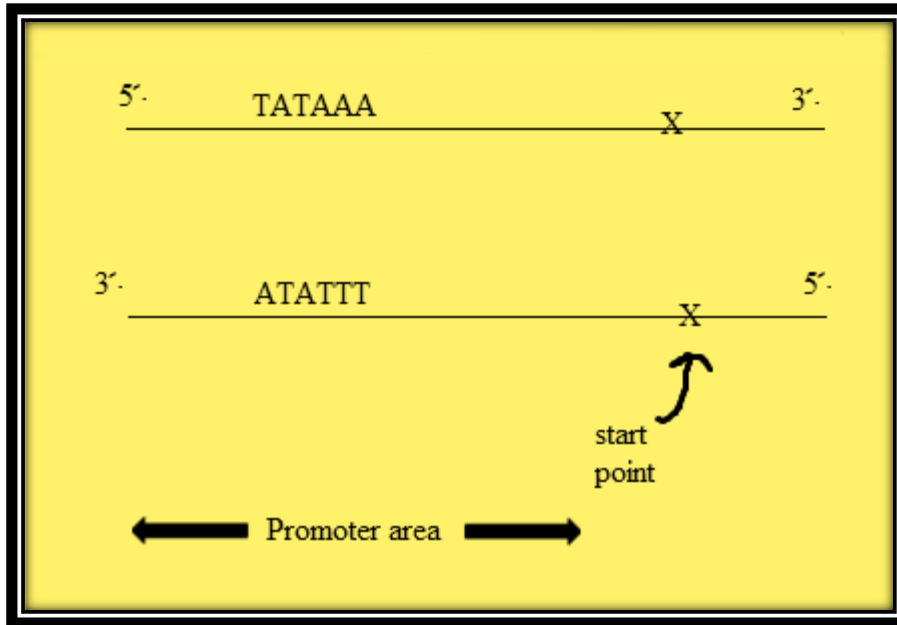
Stages of Transcription

Three stages of transcription:

Initiation: promoter binding occurs, RNA polymerase lands. The DNA helix then unwinds and the enzyme initiates RNA synthesis at the start point on the template strand.

Eukaryote promoter includes an area rich in adenine and thymine about 25 nucleotides upstream from the transcriptional start point called a **TATA box**.

Chapter 16 - Transcription

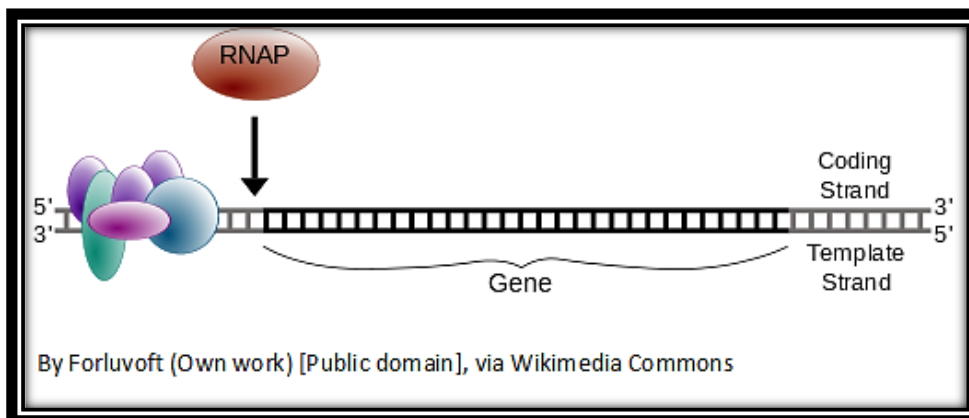


Prokaryotes have a **Pribnow box**.

Proteins called **transcription factors** recognize an area within the promoter site (TATA box) and binding occurs. These transcription factors are in eukaryotes.

Transcription factors and RNA polymerase make up the “TIC” or transcription initiation complex.

Now that attachment has occurred between enzyme and promoter region, transcription begins.



Step #2 is called Elongation

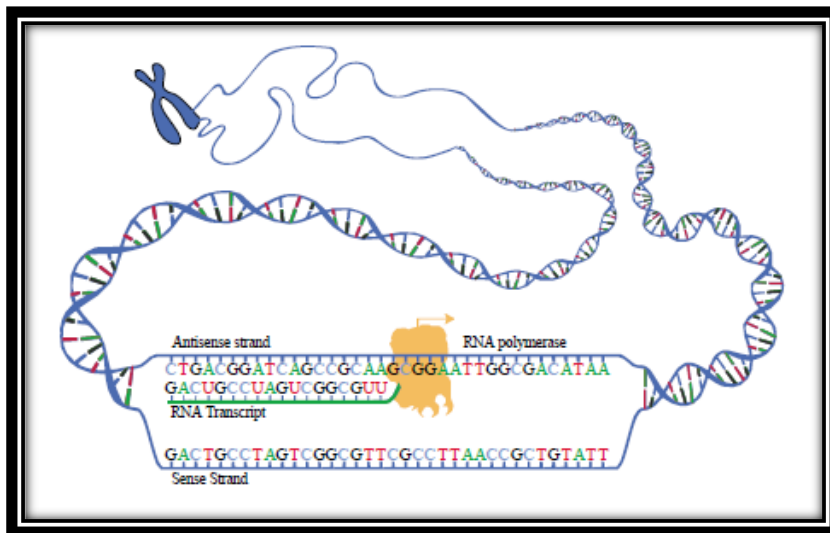
Here our RNA polymerase moves along our DNA strand and continues to untwist it. RNA nucleotides are added to the 3' end the growing chain. RNA nucleotides pair as follows: G with C and A with U.

As the complex moves down our DNA strand, the double helix can re-form. The new RNA moves away. Each transcriptional unit of three bases is called a **codon**.

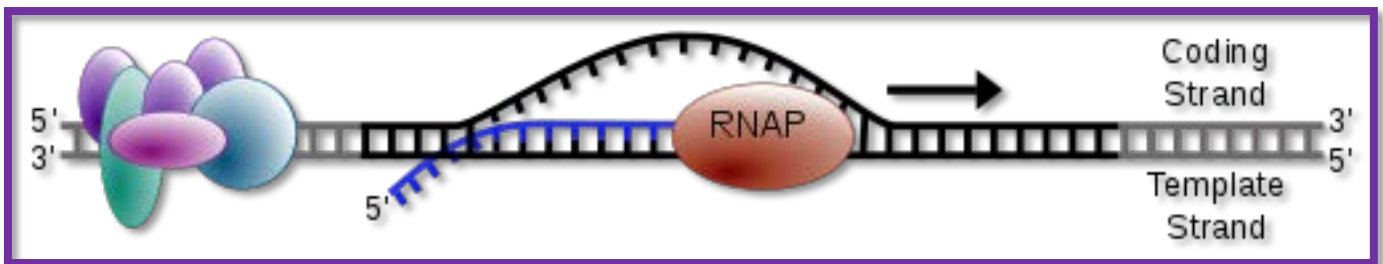
Chapter 16 - Transcription

Only one strand of the DNA is transcribed, this is our **template strand**... or anti-sense strand.

The other strand is the **coding** or sense strand.



★ Unlike DNA polymerase, RNA polymerase does not proofread for any errors... thus more errors occur during transcription than for replication. Luckily, an error during transcription gives a “bad” protein and not transmitted to the entire progeny if it occurred with DNA. ★ **Always a common exam question!!**



Now for the final part...

Termination:

We now need to remove the RNA polymerase from the DNA, therefore RNA polymerase transcribes what is called a “terminator sequence” in the DNA. Although the mechanism for terminator does differ between prokaryotes and eukaryotes, **the bottom line is this**: Detachment of the RNA polymerase occurs and our RNA transcript is released. m-RNA is now able to diffuse away from the DNA template.

Thus, to summarize: Three stages of transcription was illustrated here: initiation, elongation, and termination.

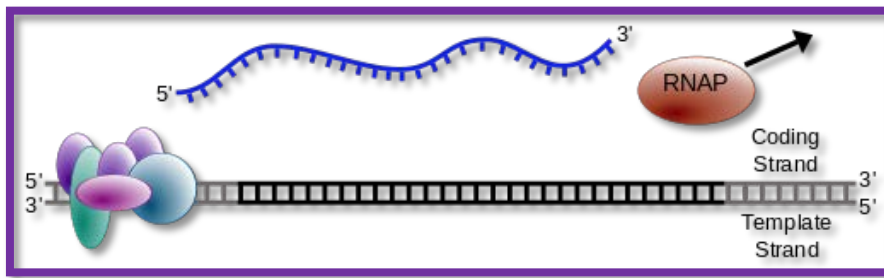
Now what?

We have newly made RNA... Does it go to the ribosome? Not so fast... a “post-transcriptional” modification must occur.

Chapter 16 - Transcription

Let's examine a few of the more important events that occur before we bind to the ribosome.

- 1) The transcript gets a “cap” at the 5' end. At the 5' end, three phosphate groups are present and easily could be degraded by enzymes such as phosphatases. A rather large moiety is placed at the end of this phosphate trio... we say we have “capped” or protected the 5' end from degradation. This enhanced the stability of our newly-formed RNA.
- 2) A polyA tail is added to our 3' end... this is simply a whole bunch of adenine nucleotides... this protects the 3' end of our RNA from enzymes like phosphatases and even nucleases.

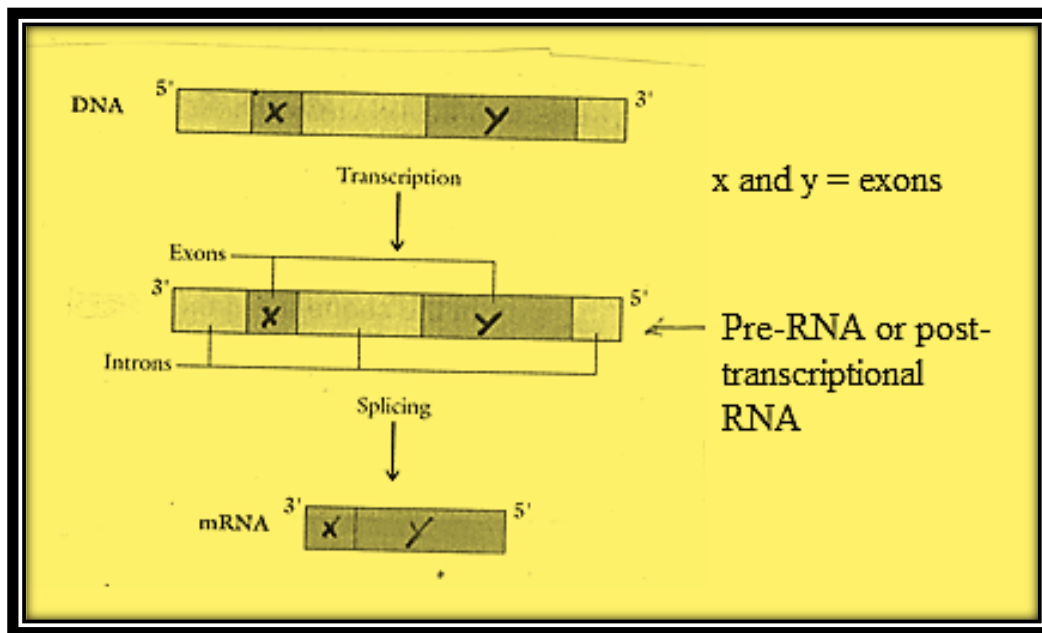


★ Studies have shown that snRNP's and other proteins form a complex called a spliceosome... it is within this big spliceosome (yes, it is big... almost the size of the ribosome!!) that the “cutting” occurs.

Bottom Line: After all this cutting... we now have our m-RNA molecule with exons!!

The mRNA that now leaves the nucleus is much smaller than the original mRNA before this “cutting” occurred.

Are you thinking what I am? This resembled a person making a video... and it was edited!! This is exactly what has occurred.



We are now ready for translation!!

Chapter 17 - Translation

Translation

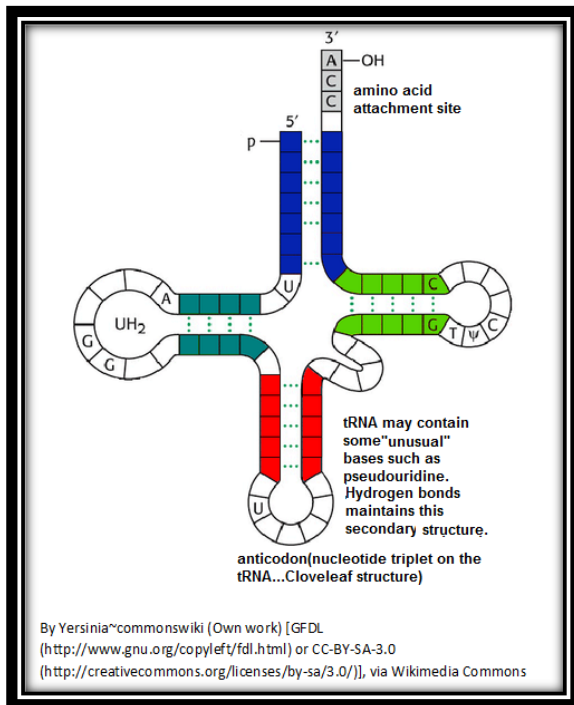
This is the synthesis of a polypeptide under the direction of RNA... occurs in the **cytoplasm**.

rRNA, mRNA, and tRNA work together outside the nucleus to form the needed polypeptide.

Polypeptides are assembled at structures called ribosomes (found in both prokaryotes and eukaryotes).

The tRNA will be involved with transferring amino acids to the ribosome.

Each tRNA is **specific** for a particular amino acid.



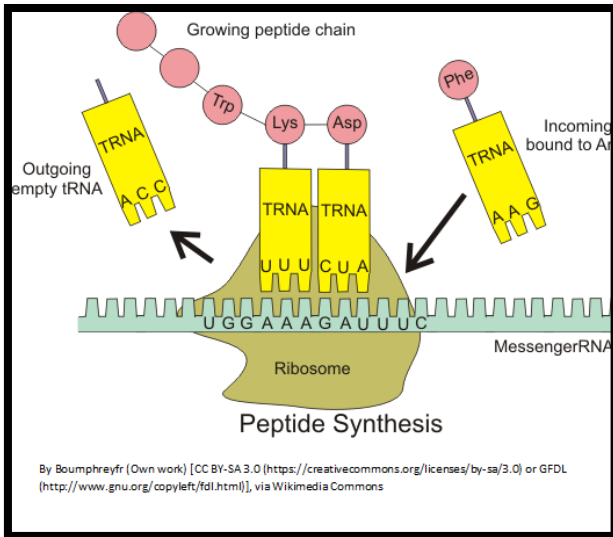
Each tRNA carries an amino acid (i.e. if we have 300 amino acids, 300 tRNA molecules are needed). The reaction that joins the amino acid to the specific tRNA is called Aminoacyl-tRNA synthetase. At least one synthetase enzyme for each amino acid exists!

This enzyme allows the amino acid to bond at the 3' end of the t-RNA.

Now, the tRNA molecule must join with the appropriate mRNA codon. A codon is an mRNA triplet... 64 codons exist... (we have four different nucleotides, taken in triplets... $4^3 = 64$).

One codon... AUG codes for the amino acid named methionine (contains a sulfur), and AUG is also a start codon.

Chapter 17 - Translation



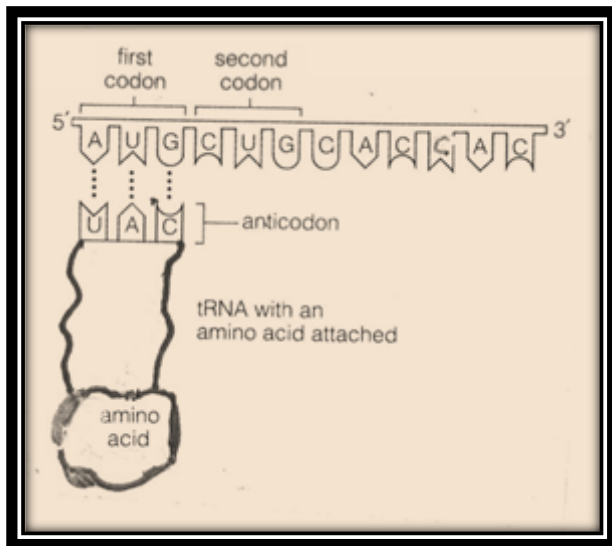
★ A ribosome has: mRNA binding site, and three tRNA binding sites: A, P, E

Polypeptide synthesis takes place at the peptidyl and aminoacyl sites... or the P and A site.

★ The P site holds the tRNA attached to the growing polypeptide chain.

★ The A site holds the tRNA with its associated amino acid to the polypeptide chain.

tRNA is discharged at the E site.



★ Eukaryote ribosomes are made in the **nucleolus** of the cell...

Eukaryotes have slightly larger size and differ in their proteins, thus, drugs can be designed to kill bacteria by targeting their ribosomes while sparing ours. Drugs such as tetracycline work by inhibiting prokaryotic ribosomal function.

Chapter 17 - Translation

The text book by Neil Campbell said it best, “the ribosome can be regarded as one colossal ribozyme!!”

(A ribozyme is an RNA molecule that functions as an enzyme... remember, ribosomes are made of proteins and RNA!)

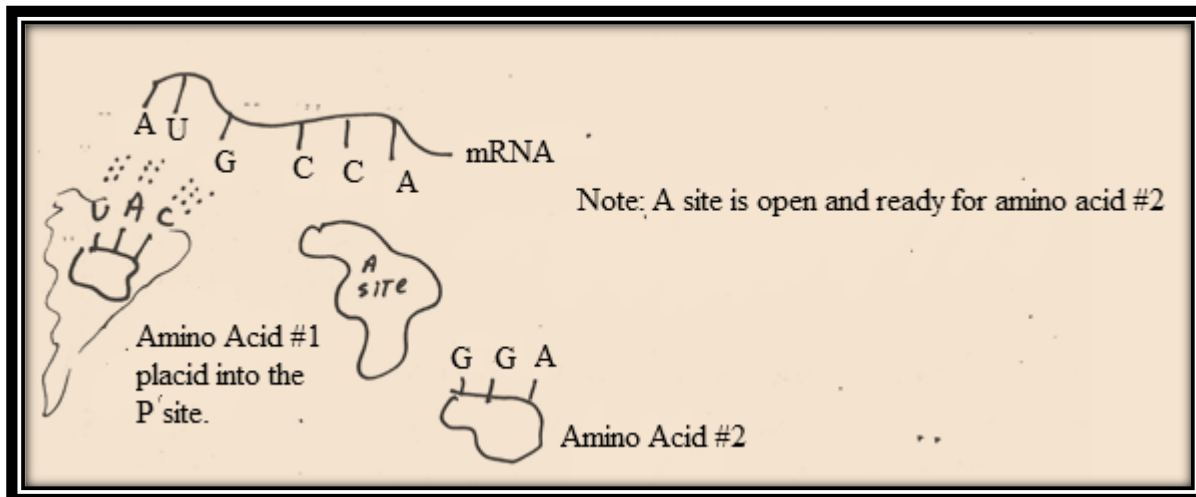
Translation Stages

Translation is similar to transcription in that it has three stages: initiation, elongation, and termination.

No need for major details, just know a few basics that I have simplified for you:

Initiation:

mRNA is attached to the ribosome. Two sites exist P binding site and A binding site. The “initiator” amino acid is loaded onto a small ribosomal subunit. The anticodon matches up with AUG to the mRNA. This is the start codon and we see this at the P site. The AUG also codes for the amino acid methionine. Next, the A site is now available to bring in amino acid #2.



A large subunit binds with this small subunit. Once this complex is formed, we are ready for the second step... elongation.

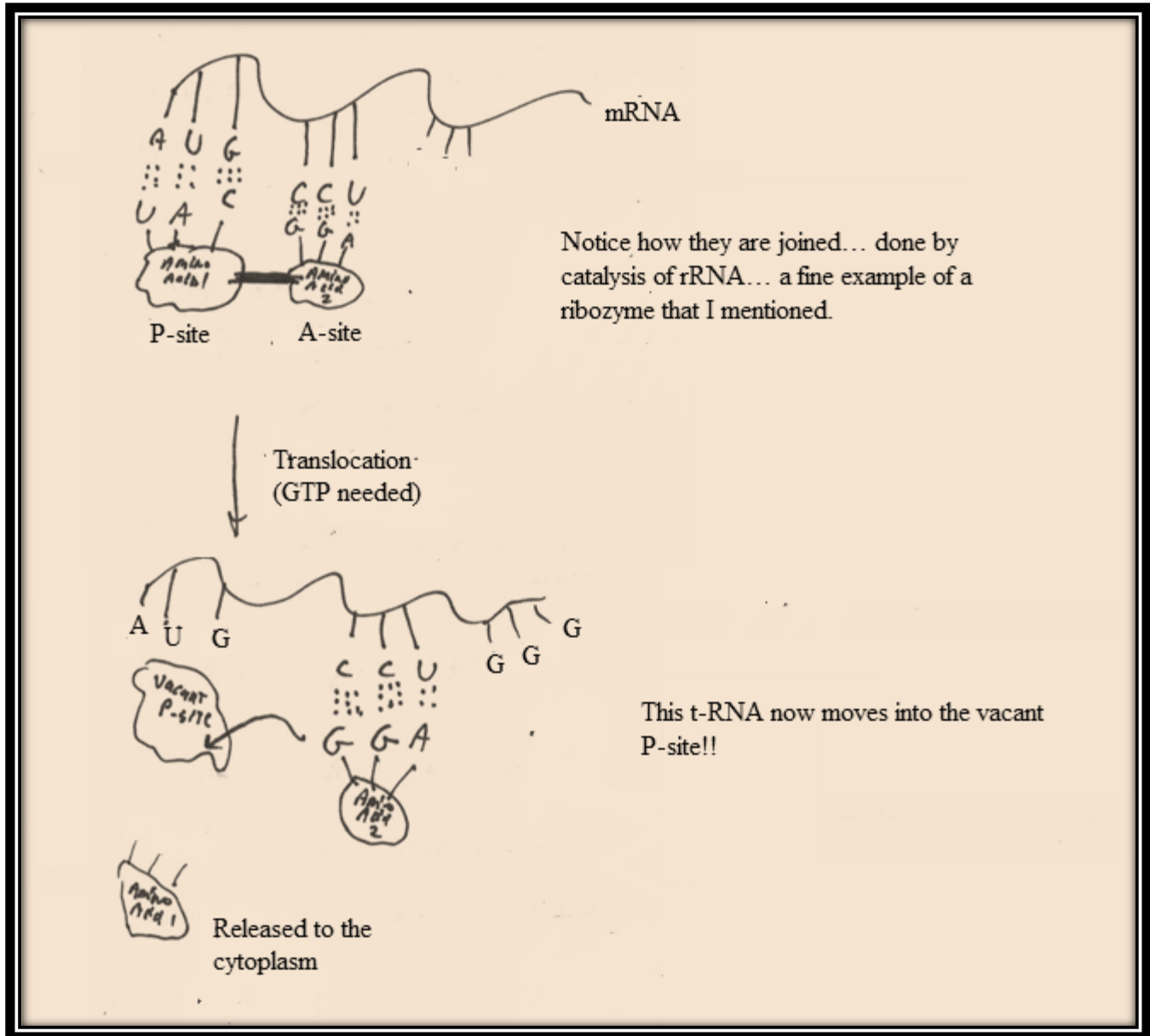
Elongation:

This is a bit tricky. We have an amino acid in the P site, and an amino acid in the A site. These two join and form a **peptide bond**. This is simple enough...

A “translocation” now occurs, whereby the tRNA that occupied the A site moves to the P site, and the tRNA that occupied the P site is moved to the E site for release!!

Let’s go back and summarize:

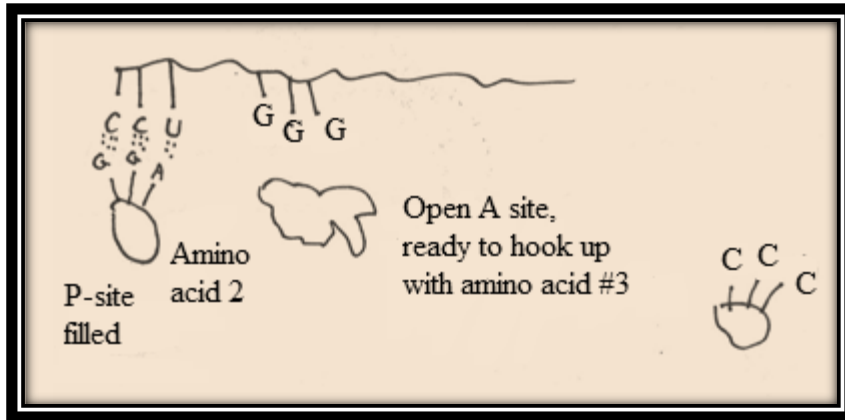
Chapter 17 - Translation



★ The 3rd base of the codon and 3rd base on tRNA might not always be complimentary... the rules are not as strict as DNA dictates... this is called a “Wobble” ... the third base pairing is less restricted... Crick developed this “**Wobble hypothesis**”.

Now, a third tRNA can move into the vacated A site.

Chapter 17 - Translation



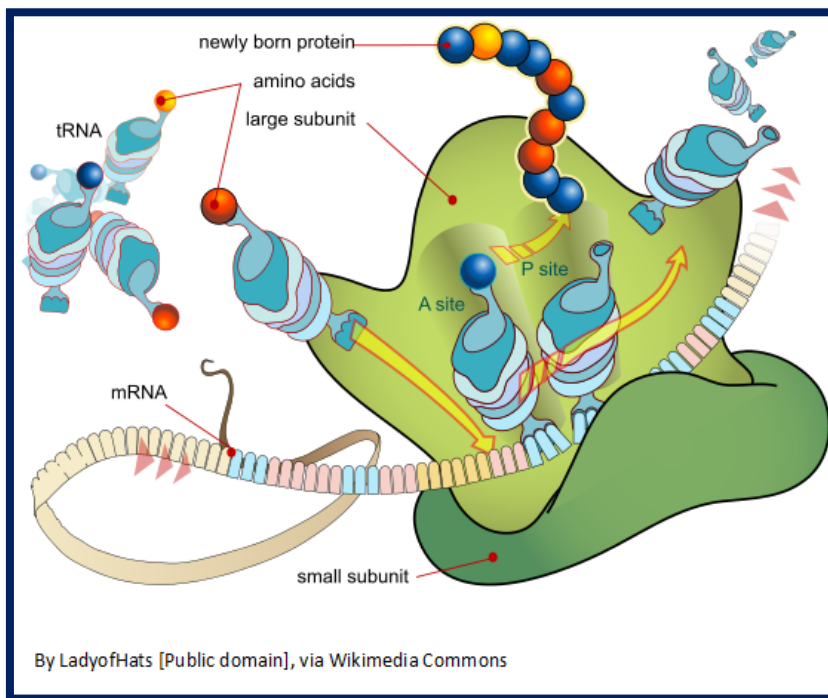
Peptide bond now forms between amino acids 2 and 3. Process now continues and amino acids are added to our growing chain.

Termination:

Synthesis will stop when a stop codon is read on the mRNA and the polypeptide is released from the ribosome. A “release factor” is a protein that binds to our ribosome. Release factors cause enzymatic activity that cause the mRNA and the chain to be released from the ribosome.

Now what?

Our newly formed polypeptide moves into the cytoplasm with other proteins or enters the rough endoplasmic reticulum to take on their final form before moving to their final destination.



Chapter 17 - Translation

Mutations

Can errors occur? Yes, indeed!

The change in the nucleotide gene sequence is called a mutation.

DNA or RNA can have mutations.

We do have some leeway here. The genetic code is “degenerate”... meaning many of the 64 codons are redundant.

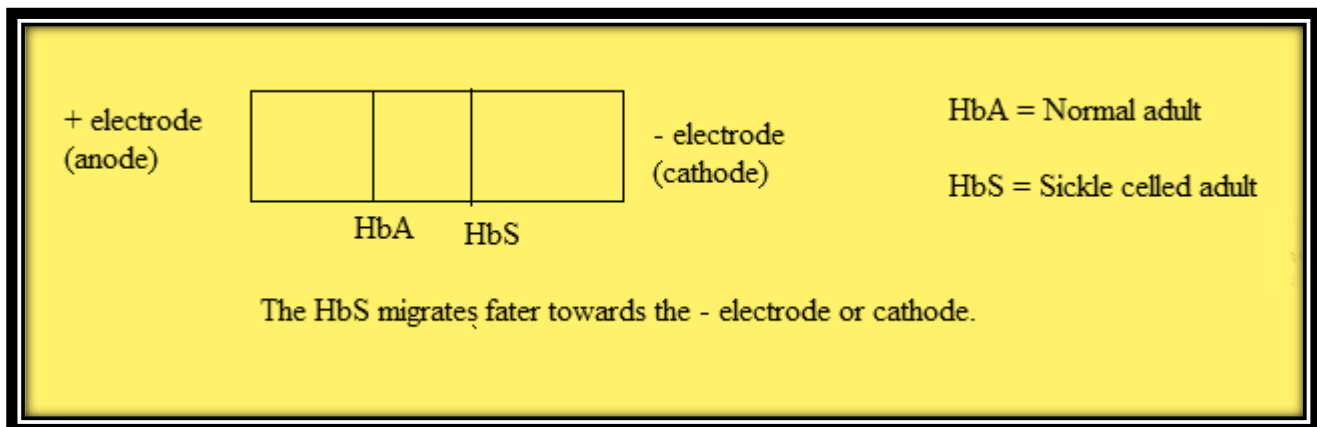
UAA, UGA, UAG → stop codons
UCU and UCC → spells serine.. if a mutation did occur where U → C at the third position, it most likely would not have a deleterious effect. However, many mutations give rise to proteins with altered or lost biological function and integrity.

Let us examine some mutations.

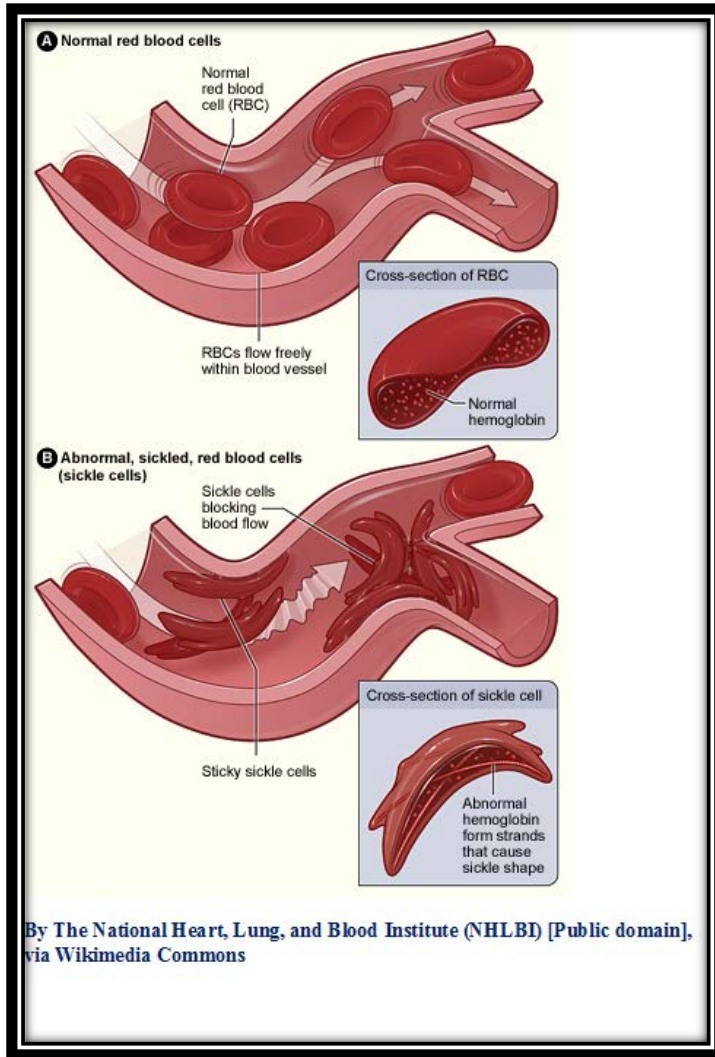
If a single base pair of gene is affected it is a **point mutation**.

In sickle cell anemia we see this type of mutation.

A glutamic acid is replaced by a Valine on the **beta chain of hemoglobin**. Red blood cells are unable to bind O₂ efficiently. The erythrocytes (red blood cells) tend to become trapped in small blood vessels cutting off circulation and causing damage to an organ. Since a glutamic acid was changed to a valine, there is one less “-“ charge... in other words, HbS (sickled-hemoglobin) is more +. This is seen when analysis is done and electrophoretic mobility is examined... see below:



Chapter 17 - Translation



2 Basic Types of Point Mutations:

A) Base Pair substitution: one nucleotide and its complimentary base in the DNA has been changed into another.

If a wrong amino acid is made, it is a **missense mutation**.

If a stop codon is made, it is a **nonsense mutation**.

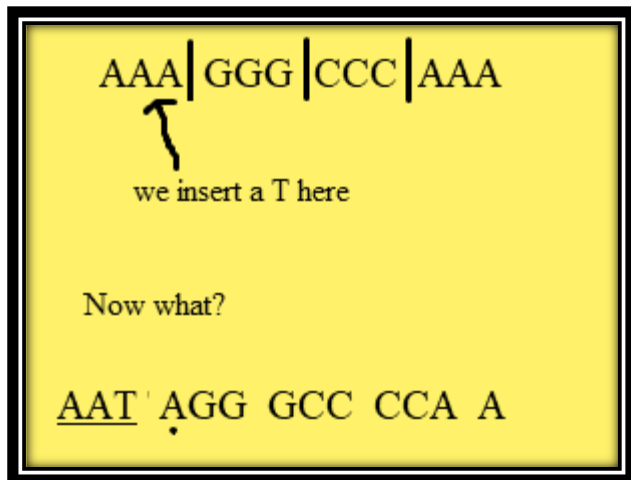


Two "must have" mutations you need to know for the DAT!!

B) Frameshift mutation:

Reading frame changes due to an insertion or deletion of nucleotide pairs in a gene.

Chapter 17 - Translation



This spelled a disaster! Each 3-nucleotide sequence downstream from the mutation has changed.

★ A base deletion near the start of a coding sequence as you have just seen would likely be catastrophic on the protein's integrity!

Transposons are “jumping genes”

which may cause a mutation when they “jump” around the genome.

Seen in both eukaryotic cells as well as in prokaryotic cells.

First discovered in the 1940's by Barbara McClintock who studied maize. She found out that transposons were responsible for many of the noted gene mutations.

In bacteria, some transposons can carry genes that make proteins for drug resistance!

What causes mutations?

Not all mutations occur spontaneously... but I have seen numbers like 1 out of every 100 billion nucleotides are altered...

A chemical or physical agent that can interact with DNA and cause a mutation is called a **mutagen**. Mutagens include X-rays and UV radiation. X-ray emanations can cause **free radicals** to be produced and repair enzymes often cannot restore proper function. DNA easily absorbs UV radiation. Often two thymine bases that are next to each other dimerize. A cell with many thymine dimers can either die or undergo malignant transformation. (Stay out of the sun, dammit!!).

A mutagen causes a mutation, but not necessarily a cancer. A **carcinogen**, however is a substance that induces a cancer.

Thus, physical mutagens include X-Rays, Gamma rays, etc.

Chemical mutagens include aromatic amines, nitrous acid, benzene

Most mutagens can indeed be carcinogens, but not always.

Chapter 17 - Translation

Review Problems

Problem #1

If DNA coding sequence is CCGAGT, the anticodon on the tRNA that binds the mRNA codon will be?

Answer:

If DNA is CCGAGT, then mRNA is GGCUCA thus tRNA is CCGAGU

Problem #2

In mRNA, every three nucleotide bases is a _____.

Answer:

Codon

1 codon = 3 mRNA nucleotides

1 codon = 1 amino acid

★ The genetic code is almost universal in the vast majority of plants, animals, and microorganisms. Exceptions do exist. For example, UGA is normally a stop codon, but in the fruit fly *Drosophila melanogaster*'s mitochondria, it codes for the amino acid tryptophan.

Chapter 18 - Regulation of Gene Expression: The Operon

Regulation of Gene Expression: The Operon

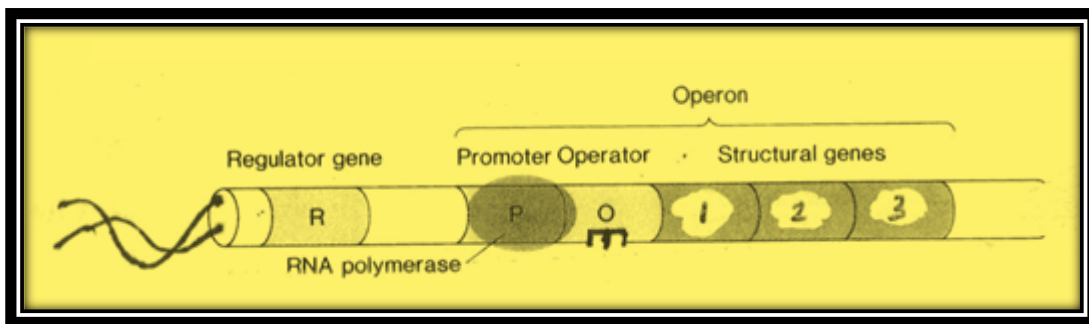
The **operon** is found in bacteria and is an important model for us to study. An operon consists of a **gene cluster**. In order for bacteria to utilize lactose, three structural genes must be transcribed to allow for lactose breakdown. These genes code for three enzymes: Permease, Transacetylase, and β -Galactosidase.

We will examine an **inducible operon**. This means it is normally turned “off”, but can be activated if needed. Later, we will examine a repressible operon, meaning it is normally turned “on”, but can be shut off when needed.

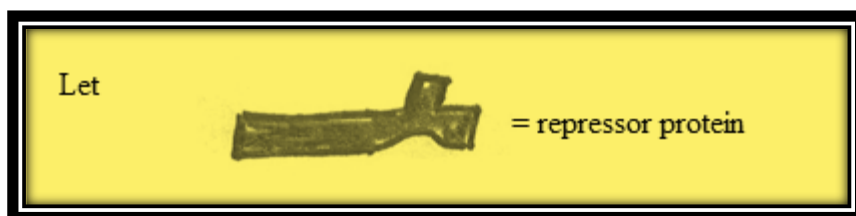
Lac-Operon

Let us examine the Lac-operon... an inducible system. A operon has three parts:

- A) **Operator**: a binding site available for a repressor protein that can prevent transcription. I like to call it the “on-off” switch.
- B) **Promoter**: the site where RNA polymerase attaches
- C) **Operon genes**:

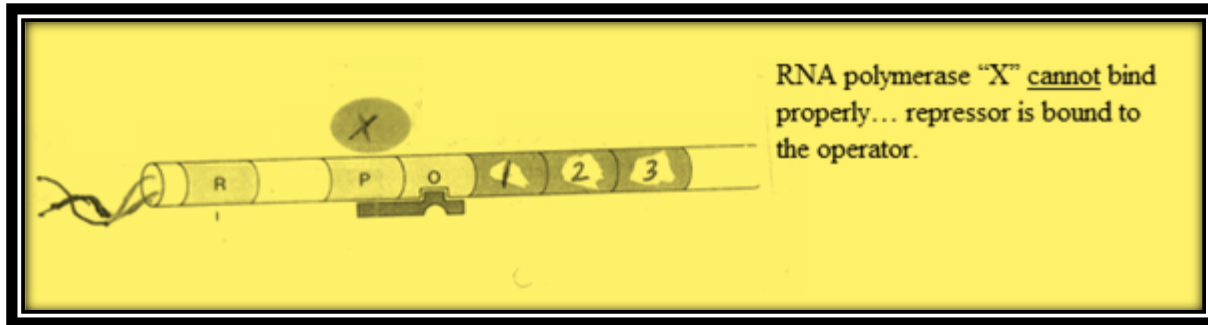


★ **Know this picture for the DAT!!**



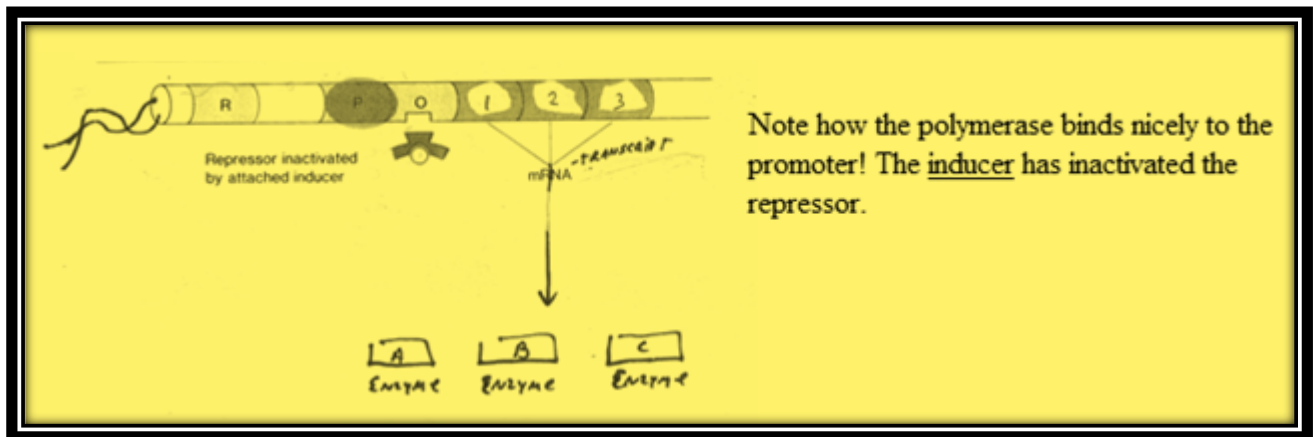
When lactose is absent, clearly, we don't need to have it metabolized. This system is shut down. How? The repressor protein binds to the operator. This bulky repressor protein takes up too much space, and prevents the RNA polymerase to bind to the promoter, thus no transcription, hence no lactose-metabolizing enzymes made!

Chapter 18 - Regulation of Gene Expression: The Operon



The repressor is part of a negative control mechanism, for genes that are prevented from carrying out the transcription process.

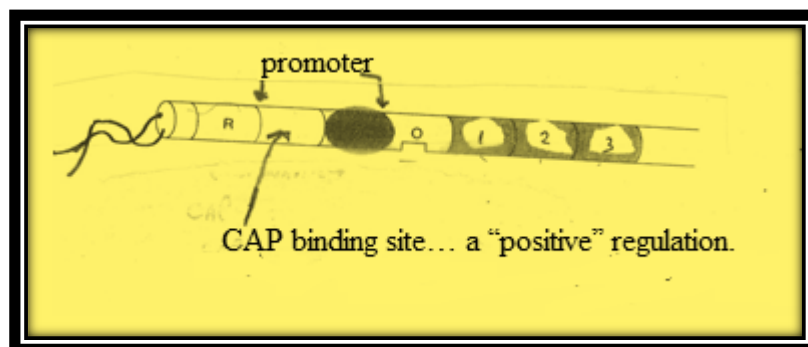
When lactose is present... it needs to be metabolized. Allolactose, an isomer of lactose formed in reasonably small numbers acts as an **inducer**. The inducer binds to the repressor and distorts its shape... this altered conformational change will prevent the repressor from binding to the operator. The promoter site is now exposed to RNA polymerase and transcription can begin!



Regulatory genes that are located some distance from the operator produce the repressor proteins.

Structural genes are in the **coding region**, while the operator and repressor are in the **regulatory region**.

★ Only when lactose is present and glucose levels are low does E. coli use lactose as an energy source, and only then, do we make these three enzymes. When glucose levels are low, cyclic AMP accumulates ... and binds to **CAP** (catabolic activator protein) ... once bound, CAP now has the proper shape to bind to the



Chapter 18 - Regulation of Gene Expression: The Operon

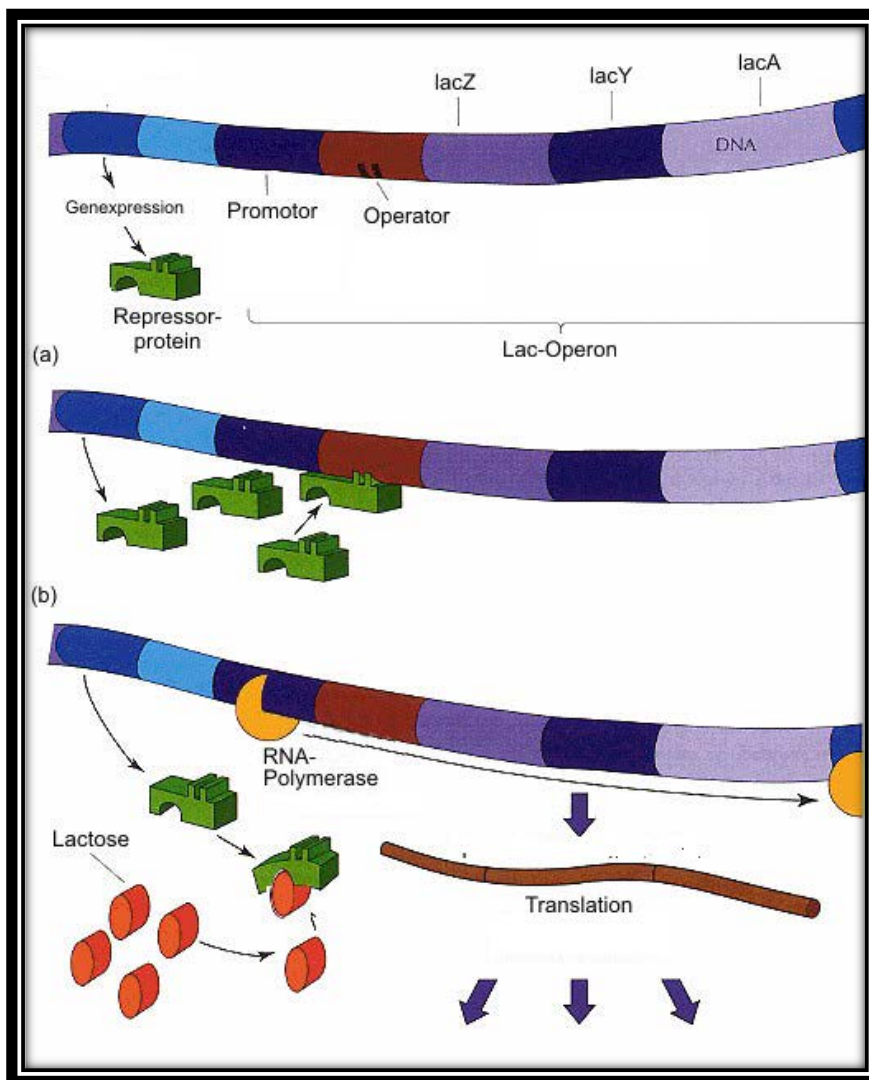
upstream portion of the promoter... this aids in the attachment of RNA polymerase to the promoter.

If glucose rises, cyclic AMP levels fall off, thus CAP binds less efficiently to its binding site... and detaches. I hope you can see this means RNA polymerase binds less efficiently and transcription decreases a great deal.

Bottom Line: The Lac operon is under a dual control:

- 1) Negative control by the lac repressor protein
- 2) Positive control by CAP.

If you understand this.. You are more than set to Destroy the DAT... it will be a joke. I have several operon problems in Destroyer and added some in our new edition book.



Trp Operon

The DAT really focuses on the lac operon, but let me briefly present the Trp operon.

Chapter 18 - Regulation of Gene Expression: The Operon

Tryptophan operon... Trp operon

Is a repressible operon ... it is also turned “on” unless a molecule called a corepressor is present.

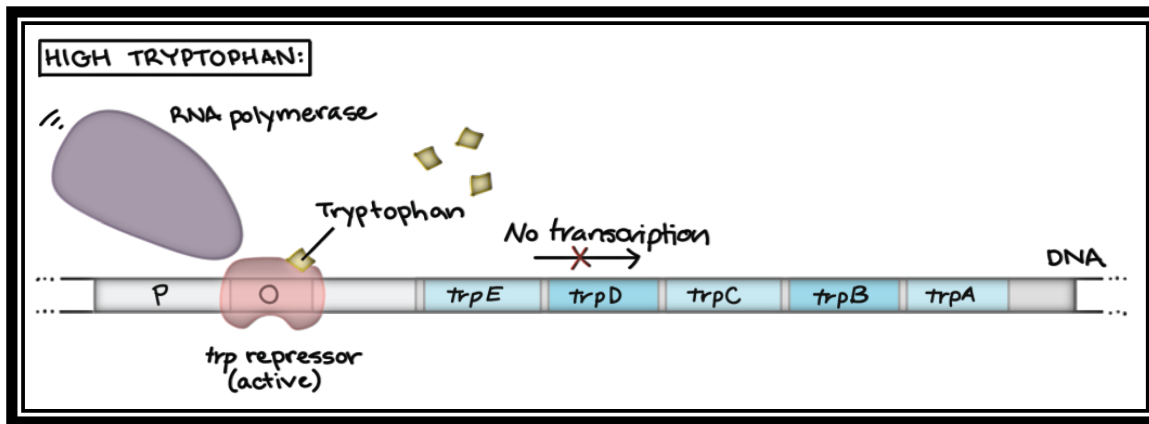
Five genes (structural genes) are involved in making the amino acid tryptophan.

This is an **anabolic process**, whereas the lac operon was catabolic.

Tryptophan = corepressor

When an inactive repressor combines with this corepressor it binds to the operator as we have seen previously... once bound... RNA polymerase can't bind... thus blocking transcription of the structural genes!

If tryptophan is present: note how the RNA polymerase can't bind.



Eukaryotic Gene Expression

Many thousands of genes are present, but only a small percent... 2% of the DNA codes for the protein. The remainder codes for RNA molecules or nothing at all.

Chromatin structure can be regulated:

- A) Genes with heterochromatin are highly condensed and not normally expressed
- B) Histones are acetylated allowing for less tightly packing of chromatin, hence allowing for better transcription... Histone acetylation promotes transcription!!
- C) DNA methylation... when CH₃ groups are added, tighter packing occurs, thus we can see a reduction in gene expression. In other words, inactivated genes are usually heavily methylated, and certain genes are activated by removal of the CH₃ group called demethylation.

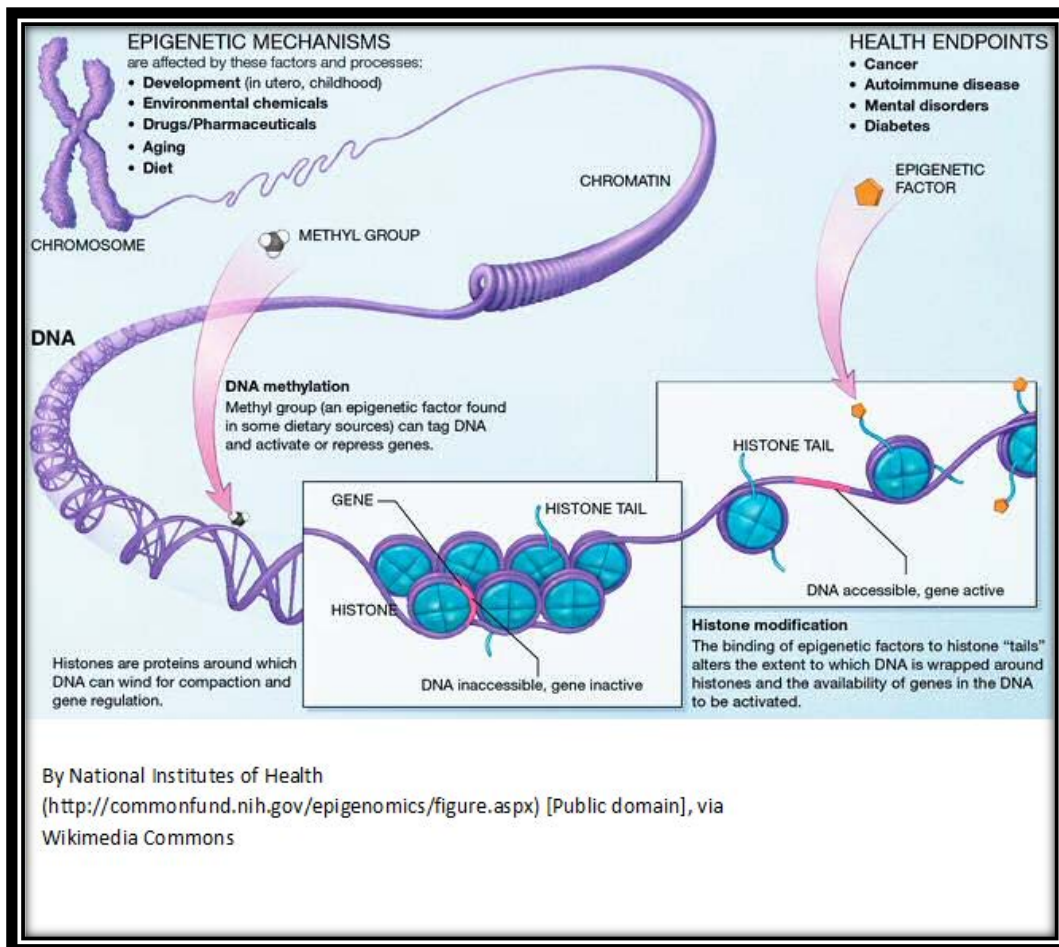
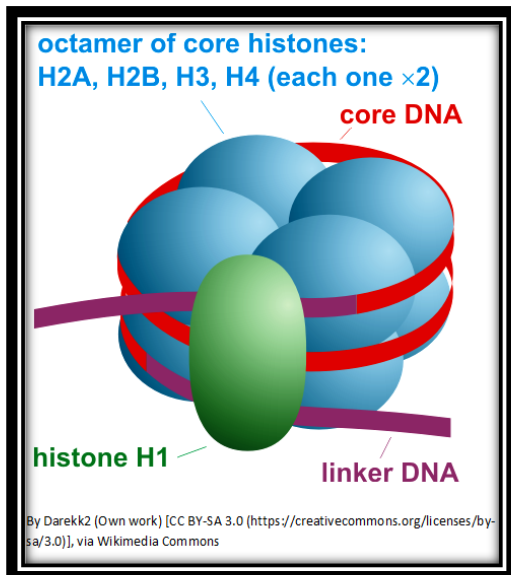
Hopefully, you can see that methylation and acetylation are two processes in a group of many that are involved in this control process. In eukaryotic organisms, gene expression rate can be increased or decreased by things such as repressors, activators, or building proteins.

Non-coding RNA molecules are now believed to be involved with gene expression control.

MicroRNA molecules miRNA and small interfering RNA molecules siRNA can bind to the mRNA. These two molecules can:

Chapter 18 - Regulation of Gene Expression: The Operon

- 1) Degrade mRNA
- 2) Bind to mRNA and therefore block translation.



Chapter 19 - Medelian Genetics

Mendelian Genetics



Gregor Mendel bred pea plants and studied the patterns of inheritance.

Chromosomes, located in the nuclei of cells contain the hereditary information that will direct the synthesis of thousands of proteins. All cells except sperm and ova are **diploid**... meaning there are 23 pairs of chromosomes or 46 total chromosomes in humans.

Each chromosome contains DNA segments that code for the basic units of heredity and are transmitted from one generation to the next. These DNA segments are called **genes**. ★ Each gene has its own location on a chromosome called a **gene locus**.

A **gamete** (haploid cell of 23 chromosomes) includes eggs and sperm.

An **allele** is a slightly different molecular form of a gene. Often one allele of a pair is dominant and the other is recessive. The allele that is dominant will mask the effect on a trait of its recessive partner.

Let A = an allele.

Let AA = homozygous dominant

Let Aa = heterozygous

Let aa = homozygous recessive

A **genotype** is the genes making you up...

A **phenotype** is the physical and physiological traits of an organism.... In other words, your observable traits.

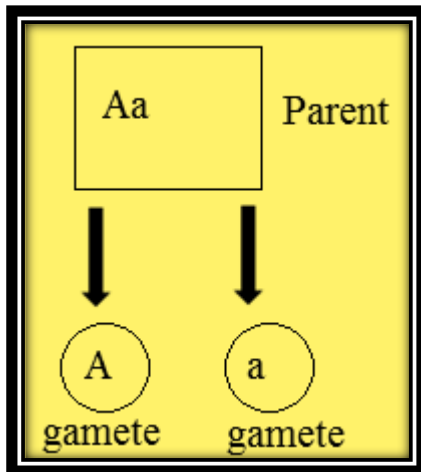
Mendel's First Law: Law of Dominance

Chapter 19 - Medelian Genetics

When AA is crossed with aa, the offspring is Aa... expressing only the dominant trait. Done as a Punnett-Square:

	a	a	
A	Aa	Aa	★ The Punnett-Square method is simply a method used to predict the outcome of a genetic cross.
A	Aa	Aa	

Law of Segregation: When gametes (egg or sperm) are made, the two traits carried by each parent separate.



Mendel's Second Law: Law of Independent Assortment

States that genes located on different chromosomes assort independently of each other. In other words, during the forming of gametes the alleles for height segregate independently from the alleles for a trait such as color. The genes for height and color are on different chromosomes and will assort independently. The closer the genes are located on a chromosome, the more likely they will be **linked**. Genes on the same chromosome are said to be linked genes.

Let us do a cross that Mendel performed on flowers:

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Monohybrid Cross



This is a cross between parents that differ in a single gene.

The Law of Segregation can be used to find the genotype and phenotype proportions.

Gregor Mendel

Let T = tall
Let t = short
 $Tt \times Tt = ?$

	T	t
T	TT	Tt
t	tT	tt

This is our F_1 generation.
1:2:1 genotype ratio

TT = 1
Tt = 2
tt = 1

but the phenotype ratio is 3:1. Why? TT and 2 Tt $\longrightarrow$ Tall
tt $\longrightarrow$ Short

A **testcross** or **backcross** can be used for an organism that shows dominance, but we are unsure if it is homozygous or heterozygous.

Let A = red color

Let a = white color



We must cross it with a homozygous recessive individual:

If we have $A_$ and we want to tell if it was AA or Aa, we cross it with aa (homozygous recessive) and note the following:

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	A	a	
a	Aa	aa	1/2 Aa → Red
a	aA	aa	1/2 aa → White

	A	A	
a	All Aa		100% Aa → All red
a			

If we get all red... our original was AA,

If we get a 50-50 mix... our original was Aa.

Dihybrid Cross

A **dihybrid cross** is a cross between individuals with two genes.

In such a cross, we start off with our F₁ offspring as AaBb.

A = purple a = white
B = tall b = short

AaBb × AaBb

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

9/16 = Purple-tall	} F ₂ Generation	9 : 3 : 3 : 1 was our phenotypic ratio...
3/16 = Purple-short		
3/16 = White-tall		
1/16 = White-short		

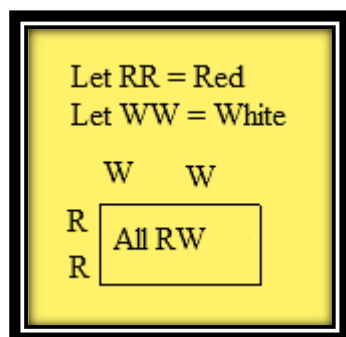
Here was evidence that genes located on two homologous chromosomes tend to travel into gametes independently of other gene pairs located on other homologous chromosomes.

Incomplete Dominance

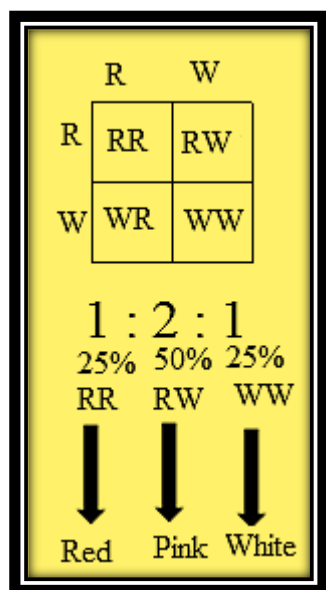
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Occurs when neither of the two alleles exerts dominance... an intermediate or “**blended**” phenotype is made.

If red-flowered snapdragons are crossed with white-flowered snapdragons, we get pink snapdragons.



Now... take RW (pink) and cross them:



Codominance

Another type of intermediate inheritance is called codominance.

In codominance, a pair of nonidentical alleles specify two phenotypes... both expressed at the same time in the heterozygote.

Here is an example:

If a person has AB blood type:

One parent gives i^A allele, other parent gives i^B allele.

We get $i^A i^B$ which is blood type AB.

The A and B alleles are said to be codominant.

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Epistatic Genes

★ An epistatic gene is a gene that covers up the expression of another gene in the phenotype. This epistasis is similar to ordinary dominance except that 2 different genes are involved. In other words, two alleles of a gene mask the expression of another gene's alleles!!

In Labrador Retrievers, we see many different colored dogs. This color difference is the result of variations in the melanin pigment. Melanin is made by a variety of enzymes which are made by gene pairs. Alleles of a different gene control the extent to which the % of melanin is deposited into the hair. The interactions between the gene pairs produce dogs of different colors. If no melanin is made, an albino will result.

Pleiotropy

Refers to a **single gene** that can affect an organism in various ways.

In sickle cell anemia, a single mutation occurs, and gives rise to a defective hemoglobin molecule. This one gene mutation causes a wide range of problems such as O₂ utilization, and tissue and organ damage.

In PKU disease, we see an unusual amount of phenylalanine in the blood. This is due to a mutant gene. Untreated patients have lower IQ's, larger heads, and lighter hair color all due to a single gene!

Can two heterozygotes give a 2:1 ratio in a Punnett Square?

	A	a	
A	AA	Aa	
a	aA	aa	

If aa = lethal gene, we get only AA and Aa thus explaining a 2:1 ratio rather than the 1:2:1 Mendelian ratio!!

Polygenic Inheritance

Here, we see **two or more genes** contributing to a single trait. Hair color, skin color, and height result from the interactions of several genes.

Height is a good example. Unlike pea plants, we don't appear as "short" or "tall"... but many different heights are seen. When several genes are involved, a bell-shaped curve is often used to describe the phenotype.

Multiple Alleles

When a gene has **more than two given alleles**.

Let us consider an example using the three allele gene... the ABO blood type in humans.

There could be four possible phenotypes A, B, O, AB... all produced from combinations of three different alleles: i^a, i^b, and i^o.

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Types O and AB are produced from a single genotype, but A and B may be either homozygous or heterozygous.

To Review:

Blood Type	Possible Genotypes
A	$i^A i^A$, $i^A i^O$
B	$i^B i^B$, $i^B i^O$
AB	$i^A i^B$
O	$i^O i^O$

Type O = Universal Donor

Type AB = Universal Recipient

What could result if a heterozygous man for Type A blood and a heterozygous woman for Type B blood had a child?

Set up a Punnett Square!

	i^B	i^O
i^A	$i^A i^B$	$i^A i^O$
i^O	$i^O i^B$	$i^O i^O$

25% of children = Type A

25% of children = Type B

25% of children = Type AB

25% of children = Type O

Type A blood has “A” surface antigen... but no B.

Type B blood has “B” surface antigen... but no A.

Type AB blood has both A and B surface antigen.

Type O blood has neither A nor B surface antigen.

Type A blood, for example has “A” surface antigens, thus obviously no anti-A-antibodies will be made since it would destroy them. If Type B blood was injected into a Type A person, anti-B-antibodies in their plasma

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will recognize the “foreign invader” and **clumping** or **agglutination** would occur to cleanse the blood to foreign protein.

Type O do not produce antigens; thus, their blood is not normally rejected. Those with Type AB blood do not make any antibodies... this blood type does not discriminate, thus can be the universal “recipient” in transfusions....

Summary

Type A: A antigens on surface; B antibodies in plasma

Type B: B antigens on surface; A antibodies in plasma

Type AB: A and B antigens on surface; No A and No B antibodies in plasma

Type O: No A and No B surface antigen; B and A antibodies in plasma

This is an important DAT topic, make sure you understand this. I have put some fair-game problems in Destroyer that you will find challenging to reinforce this!!!

Sex Linkage

Genes on the X or Y chromosome are said to be sex linked. Generally, we don't deal with many Y-linked traits, known as holandric inheritance. **For the DAT exam, you will see X-linked diseases only.**

Some **X-Linked diseases**:

- 1) Color blindness
- 2) Hemophilia
- 3) Duchenne Muscular Dystrophy

Each egg: has an X chromosome

Each sperm: has X or Y chromosome

Females (mammals) have 1 chromosome that is inactivated in embryonic development by methylation... called a **Barr Body**.

A male is XY... **hemizygous**.

Over 150 genes have been assigned to the X chromosome, very few are known on the Y chromosome.

I will use the following notation:

XY = normal male

$X^C Y$ = colorblind male

XX = normal female

$X^C X$ = carrier female

$X^C X^C$ = colorblind female

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Most sex-linked or commonly called “X-linked” diseases are **recessive**... meaning a male has the disease since men have only a single X chromosome, but a female with one “bad” gene would only be a carrier! Females must be homozygous.

Let’s try a few DAT-style problems:

Problem #1

A normal male and a colorblind female have a child. Show the possible outcomes.

	X^c	X^c	
X	X^cX	XX^c	100% sons are colorblind.
Y	X^cY	X^cY	All daughters are carriers.

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Problem #2 Part A

A hemophiliac male and a carrier female for hemophilia have a child. Show the possible outcomes.

	X^H	X
X^H	$X^H X^H$	$X^H X$
Y	$X^H Y$	XY

50% boys are normal

50% boys have hemophilia

50% girls have hemophilia

50% girls are carriers

Problem #2 Part B

What is the probability to have a boy who is normal? **A DAT favorite!**

The probability to have a boy is $\frac{1}{2}$.

The probability to have a normal boy is $\frac{1}{2}$.

Thus, $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ or 25%.

Problem #3

A woman is a carrier for a sex-linked recessive trait. She has two boys with a man who has this disease. What is the probability that both boys have the disease?

XX^* is a carrier women, where * means the “bad gene”.

	X^*	Y
X^*	$X^* X^*$	$X^* Y$
X	XX^*	XY

The probability for one boy is $\frac{1}{2}$... for two boys... $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ or 25%.

Non-sex chromosomes are autosomes... let us do some problems here.

Autosomal Recessive Inheritance

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These diseases include **cystic fibrosis** (defect in Cl^- channel protein... excessive mucus is made, infections occur often).

PKU disease (unable to metabolize phenylalanine)

Albinism (absence of melanin... a pigment that protects you from skin cancer).

Both sexes affected **equally**.

Can appear to **skip** generations (i.e. a girl and her grandmother are afflicted).

★ A = Autosome

= bad gene

A^+A is a carrier

A^+A^+ has the disease

Problem:

Two carriers for Albinism, an autosomal recessive disorder have a child. Show the possible outcome.

	A^+	A
A^+	A^+A^+	A^+A
A	AA^+	AA

$A^+A^+ = 25\%$ have disease

$A^+A = 50\%$ are carriers

$AA = 25\%$ are normal

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Autosomal Dominant Inheritance

No sex preference, no skipping of generation!!

If one gene is affected, you have the disease. i.e. A^*A or A^*A^* = disease

Examples include **Achondroplasia** (dwarfism) and **Marfan syndrome** (connective tissue disorder)

Problem:

If 2 people, both are heterozygous for neurofibromatosis (an autosomal dominant disorder) have a child; show the possible outcome.

	A^*	A
A^*	A^*A^*	A^*A
A	AA^*	AA

75% have disease (A^*A^* and A^*A = disease)

25% are normal

Points to Remember for the DAT:

Males give sex-linked genes to their daughters... not their sons.

Males only give sons Y chromosome

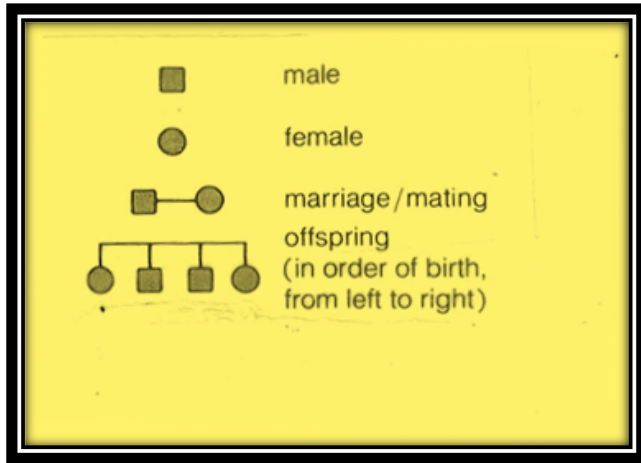
Females give sex-linked genes to both sons and daughters

A male gets a sex- linked disease from his mother!!

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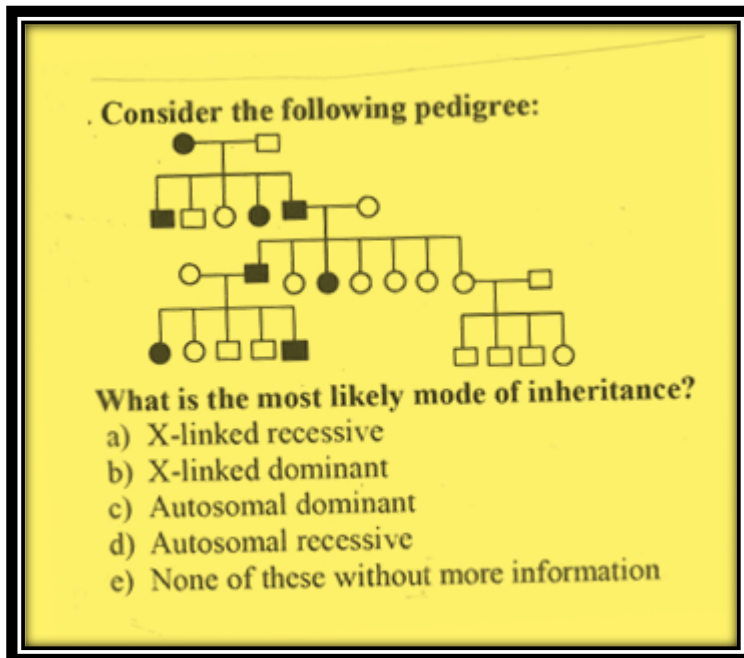
Pedigree

This is a diagram that shows genetic relationships of individuals. Genetic abnormalities and inheritance patterns can be identified.



Let's do 2 DAT Destroyer problems to illustrate what you could see on the DAT exam.

Problem #1:



Assume X-linked for openers.

Our female has the disease... X^X . The two dots = bad gene. Notice not all the boys have the disease; this is not X-linked!!

Secondly... there is no sex preference which suggests an autosomal disorder.

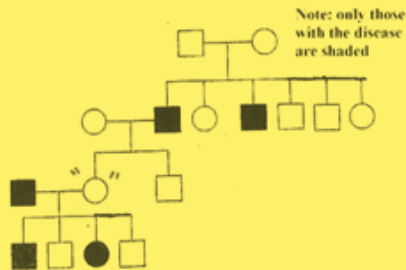
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Lastly... there is no skipping... thus not autosomal recessive... recall autosomal recessive skips.

This is therefore an autosomal dominant disorder... choice C.

Problem #2:

Consider the following pedigree :



Which statement is true?

- a) The mode of inheritance is most likely autosomal dominant
- b) The mode of inheritance is most likely sex-linked dominant
- c) The mode of inheritance is most likely sex-linked recessive
- d) Holandric inheritance - carried on Y chromosome is the mode of inheritance
- e) The mode of inheritance is most likely autosomal recessive

No skipping of generations... autosomal recessive unlikely. Clearly, the male at the beginning is normal, since box is not shaded. Let's assume ... our lady is a carrier. She would give either a "good X" or a "bad X" to her children. Now... look at mating... the must have given the daughter the "bad gene" she is represented as "○" and she is a carrier. This is confirmed in the last mating of The woman carrier (X⁻X) gave the final son the "bad gene", the other two sons the "good gene"... and the daughter got the "bad gene" from both the mother and father. This is sex-linked recessive. C.

Great practice for the DAT... you can do them all if you followed this!

Linkage and Crossing Over

Linkage refers to the tendency of genes which are located on the same chromosome to stay together.

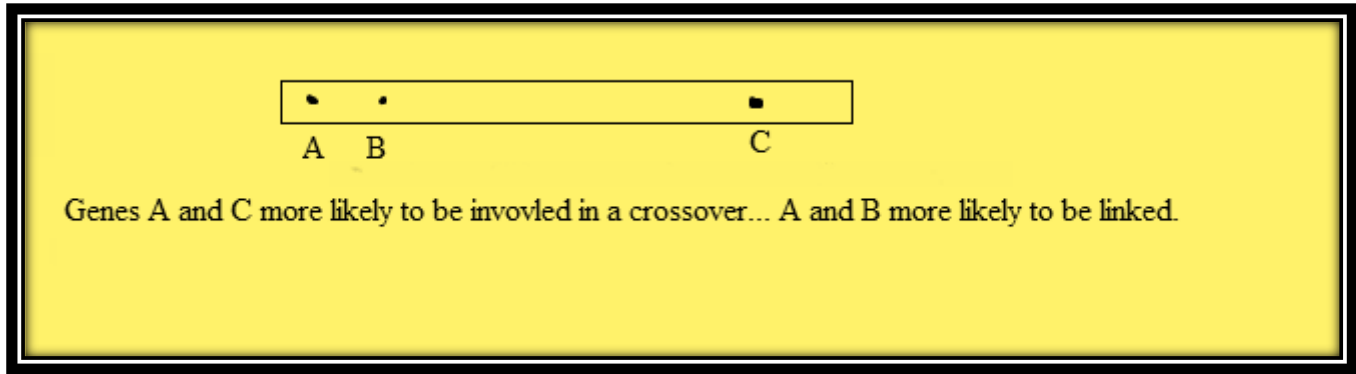
Linkage could be disrupted when crossing over occurs during meiosis.

The farther apart the two genes are on a chromosome, the greater the frequency of **crossover** and **recombination** between them. The result of a crossover is what we call a recombination.

A **linkage map** can be made that is based on the % of cross-overs!!

Linkage map of 3 genes:

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★ The probability of a crossover is proportional to the distance separating the genes!!

Chromosomal Abnormalities

Nondisjunction

Failure of homologous chromosomes to separate in Anaphase I or II of meiosis

95% the cause of **Down syndrome**

As a result... the offspring will have the wrong number of chromosomes. This is called an **Aneuploidy**.

Most nondisjunction's affecting autosomes are lethal, especially if a loss of an autosome occurs. However... not always!

Turner Syndrome:

A female that is just 1 X

No Barr Bodies in this sterile female with poorly developed ovaries and incompletely developed secondary sex characteristics. Only viable monosomy known in humans.

Klinefelter syndrome:

A male with XXY

Sterile male with feminization

Down syndrome:

An extra #21 chromosome "Trisomy 21"

Mental retardation

Heart defects

More prone to Alzheimer's and Leukemia

What is a Polyploidy?

This is very common in plants. We see a 3N or 4N cell! Many weeds, dandelions, and wild oats are polyploid.

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Endosperm of plant seeds: $3N$

Human liver cells are occasionally $3N$, $4N$, etc.!!

Structural Changes in Chromosomes

Deletion:

A break occurs and a fragment is lost and we note missing genes

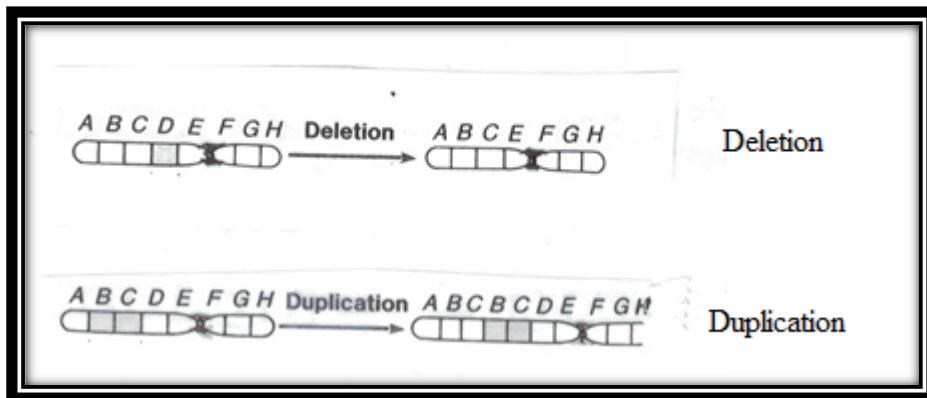
Chromosomal deletions are associated with some cancers!

If the short arm of Chromosome #5 is deleted... Cri du Chat syndrome...

Duplications:

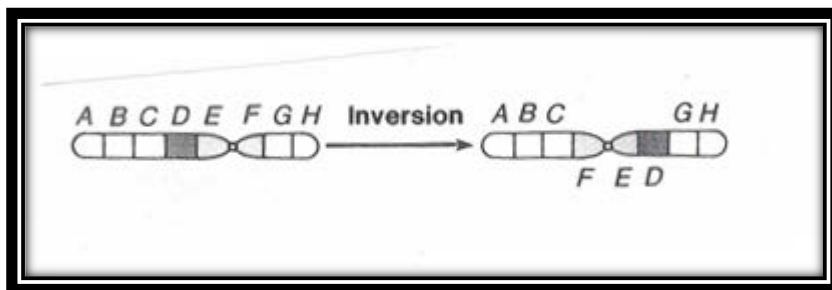
An addition is now added on to a chromosome from one that is fragmented. Partial Trisomy results.

★ Chromosomes may be broken down by radiation, various chemicals, or even viruses.



Inversion:

A chromosome segment is turned 180°



★ Translocation:

A deleted chromosome fragment is joined to a nonhomologous chromosome.

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Can account for the fact that in Down syndrome... 5% of the time we see what is called a Robertsonian Translocation... Translocation of the chromosome 21 long arm onto the long arm of chromosome 14.

The key word here is **nonhomologous**.

Genetic Testing

Sometimes genetic testing can be done on a fetus to find out if any genetic abnormalities are present. Let us have a brief look:

Amniocentesis

Amniotic fluid of the fetus is sampled. Fetal secretions and epidermal cells from the Respiratory and GI tract can be cultured and subjected for karyotypic analysis.

Ultrasound

Fetus is visualized to see any morphological defects prenatally.

CVS (Chorion Villus Sampling)

A sample of the placenta is physically removed. Chorionic tissue is rich in cells, hence karyotypes can be done in a timely fashion. ★ Slightly higher risk than amniocentesis.

To find the number of gametes given a genotype:

Use 2^n rule n = number of heterozygotes

How many gametes can be made given the following genotype: Xx Yy Zz WW BB

$$2^3 = 8$$

Why? Three heterozygotes were here, thus $n = 3$.

The DAT loves this type of problem!

Chapter 20 - Cell players - Circulatory and Immune System

Cell players of the Circulatory and Immune System

Player #1: Red Blood Cell (RBC) or Erythrocyte

Live about 120 days

Lack a nucleus when matured; biconcave shaped

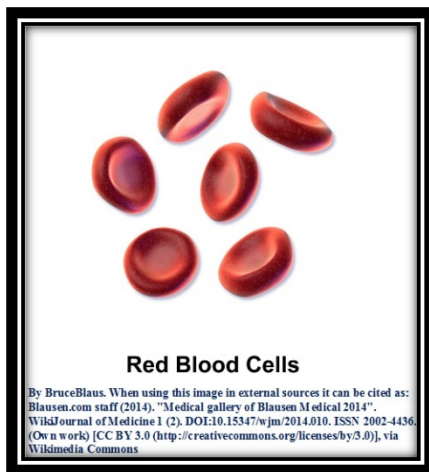
Packed with hemoglobin, which carries O₂ to tissues

The shape allows this cell with a large surface-to-volume ratio that helps in gas exchange

About 250 million Hemoglobin molecules are in a red blood cell

In Anemia, we see a decrease in the number of RBCs

Very flexible, can easily change shape when it passes through capillaries



What is a reticulocyte?

- An immature red blood cell
- 1% of RBC's
- Have no nucleus
- Mature in about a day to a mature RBC

During maturation RBCs lose their ribosomes, mitochondria, and many cytoplasmic enzymes, thus they produce ATP by glycolysis.

Macrophages of the spleen and bone marrow and even liver (Kupffer cells) dispose of RBCs after 120 days!

Where are RBC's produced?

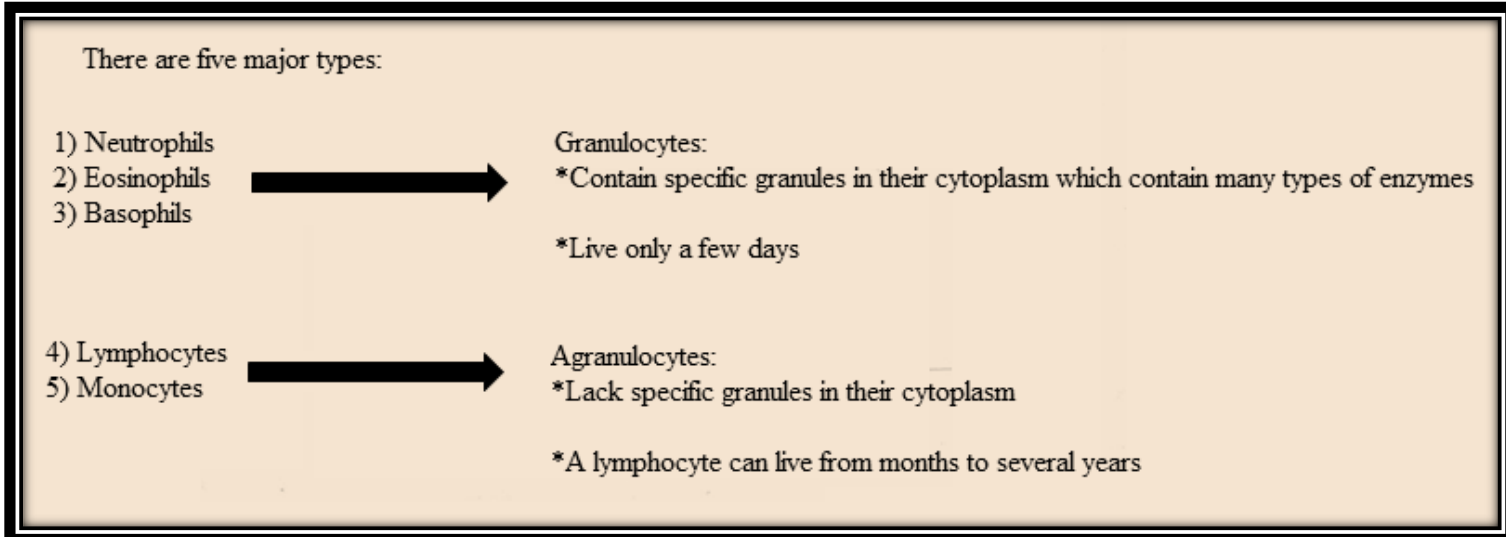
- In the embryo, the main RBC production site is the liver
- Otherwise... they are continuously made in the red bone marrow

Chapter 20 - Cell players - Circulatory and Immune System

When stained with Giemsa or Wright stain, they are pinkish in color!

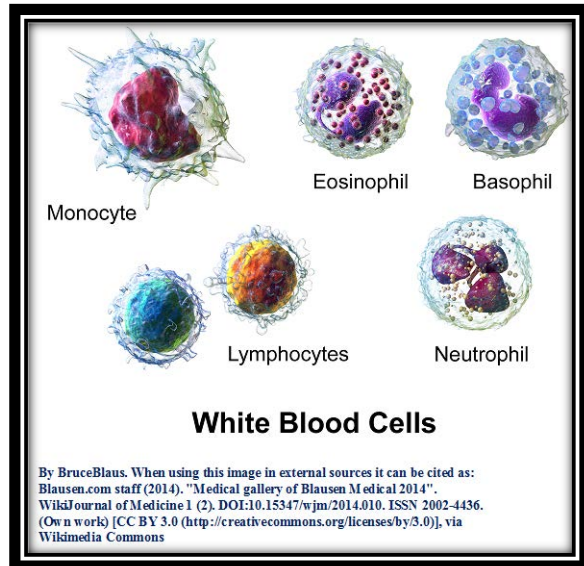
Player #2: White Blood Cell or Leucocyte

Their #1 function is to fight infections!



Neutrophils: most numerous ~65%

Basophils: least numerous- under 1%



Leucocytes can leave the bloodstream by what is called **diapedesis**. Injured tissue releases chemical signals that cause **vasodilation** of capillary walls and postcapillary venules and allow for **migration** from the blood to connective tissues. This greatly increases during times of inflammation, which is a vascular and cellular defense-type reaction in response to invaders such as bacteria.

Inflammation Involves:

Chapter 20 - Cell players - Circulatory and Immune System

- a) Redness: due to increased blood flow
- b) Swelling: due to increased capillary permeability
- c) Heat: due to more blood
- d) Pain: nociceptors are stimulated because of the increased fluid pressure
- e) Disturbed function

In Histology and Pathology, details of these cells will be examined. Books can be written on them. For our purposes, only a brief description is needed for the DAT exam. Here are a few pertinent facts:

Neutrophils are usually the “first responders” to appear in acute bacterial infections, and are very active in phagocytosis!! As you can imagine... this neutrophil is the most abundant phagocytic cell.

Bottom Line: Neutrophils are the first line of defense against invading microorganisms

If you have an infection, you likely have a fever. A fever is caused by numerous bacterial products such as endotoxins.

Eosinophils are involved in destroying parasitic worms and participate in allergic reactions. However, they have very low phagocytic activity.

Basophils: Our least numerous WBC. Their main job is to initiate the process of inflammation. This cell can do phagocytosis. Indeed, a key “player” in asthma, anaphylaxis, and, hay fever. This cell can produce histamine that induces inflammation (it is a vasodilator) as well as heparin, which prevents blood clotting.

Lymphocytes: these cells can be small, medium, or large and actually constitute an entire family that can live for years!

B-Lymphocytes: responsible for humoral immunity... antibodies!

- o B-cells differentiate into plasma cells which make antibodies

T-Lymphocytes: responsible for cell-mediated immunity!

Some T-cells differentiate into:

T-Killer Cell (NK Cell): can kill a cancer cell. In just hours, these NK cells can kill tumor cells, infected by a virus. NK cells also secrete cytokines (cytokines are peptides or glycoproteins of low molecular weight. They act on cells that have receptors for them) which are essentially the “hormones” of the immune system. Much work and much debate still goes on about this cell.

T-Helper Cells: can release cytokines as well as help activate B cells to secrete antibodies and macrophage activation.

T-Suppressor Cells: involved with regulation of both humoral and cell-mediated responses.

Monocytes: the largest of the circulating blood cells!

Differentiate into **macrophages**. Macrophages are loaded with lysosomes since they are avid phagocytosing cells, and they produce cytokines that activate inflammatory processes. Bone marrow derived!

Chapter 20 - Cell players - Circulatory and Immune System

As you can see, monocytes and macrophages are the same cell but in different stages of maturation. In histology class, you might hear them called different names! For example:

- In the liver, they are called Kupffer Cells
- In the skin, they are called Langerhans Cells
- In the bone, they are called Osteoclasts
- In the CNS, they are called Microglial Cells

These cells have many Golgi complexes and Lysosomes.

Macrophages = Big Eaters!

In response to large molecules that are foreign to the cell, macrophages can fuse to make up what is called a Foreign Body Giant Cell... which is now a size that is ready to fight!!!

Player #3: Mast Cell

Produces histamine, heparin and leukotrienes

Live only a few months

If **histamine** is released by these cells, localized edema occurs and your mucosa swells and you feel “stuffy” and breathing is hard. Victims of hay fever know this too well. Histamines open up or dilate capillaries and make them permeable. Increasing the diameter of the capillary allows more clotting proteins and phagocytes delivered to the injured area.

Their main function is to store the mediators of the inflammation process!

What is a leukotriene?

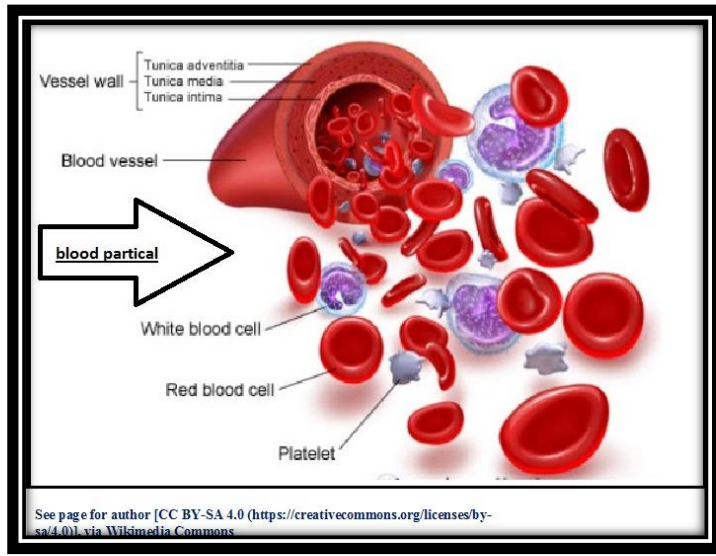
A molecule that stimulates the contraction of smooth muscle and enhances vascular permeability. In other words, a person gets an asthma attack and has a hard time breathing. Leukotrienes have caused a

★ **All derived from a hematopoietic stem cell**

bronchospasm!

Chapter 20 - Cell players - Circulatory and Immune System

Player #4: Platelets (Thrombocytes)



Involved with blood clotting

Live about 2 weeks

No nucleus

If a blood vessel is injured, platelets combine with collagen (a fibrous protein) and become activated. This activation leads to a clot. In a blood clot, we see **fibrin** aggregating into thin threads, along with RBCs, WBCs and platelets. This gelatinous structure is what we call a blood clot or **thrombus**.

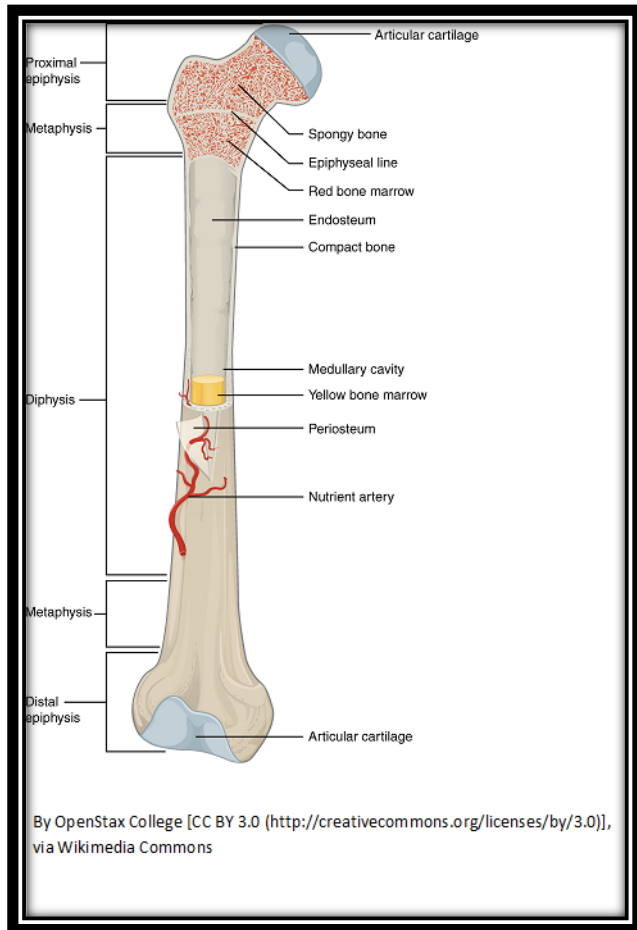
Platelets originate from giant cells located in the bone marrow called **Megakaryocytes**. Technically, they are not cells, but small fragments of cells!!

Now... let us examine cell abundance (know this for the DAT!):

Red Blood Cells > Platelets > White Blood Cells (in terms of abundance)

Chapter 20 - Cell players - Circulatory and Immune System

Bone Marrow



Red Bone Marrow:

Makes RBCs, WBCs, and platelets

Red due to hemoglobin

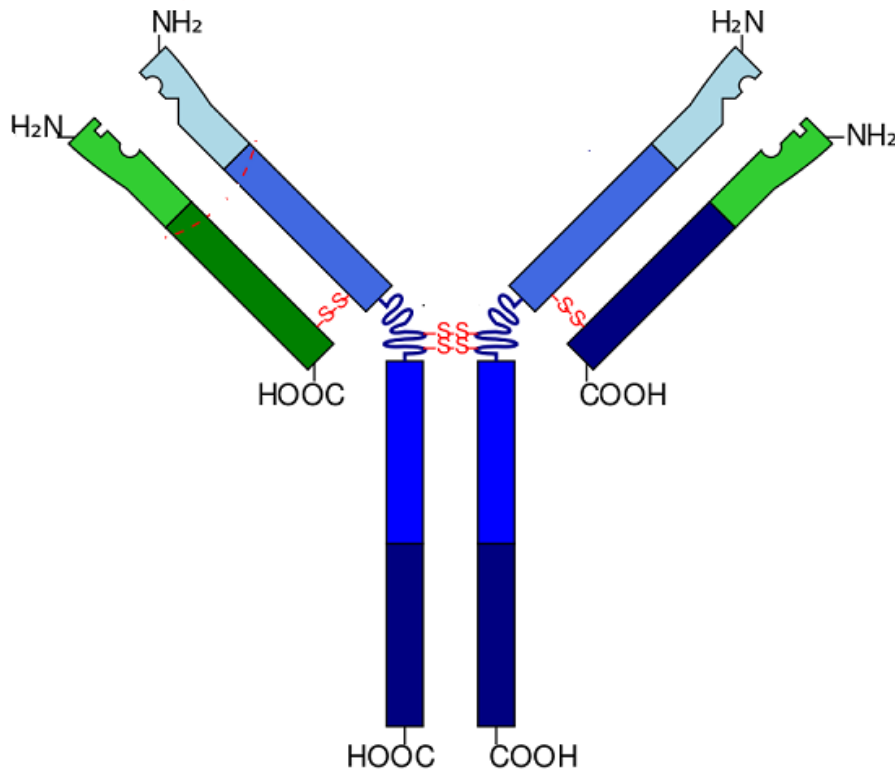
Found in all bones at the time of birth, but by the time we are 15 or so, it is confined to the **axial** skeleton (skull, ribs, vertebral column)

Yellow Marrow: appears microscopically as fat tissue and is seen in the bones of the limbs.

★ In times of severe blood loss, yellow bone marrow can transform into red bone marrow to allow for more hematopoiesis (forming of blood cellular components).

Chapter 20 - Cell players - Circulatory and Immune System

Immunoglobins



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via Wikimedia Commons

These are protein molecules that act as antibodies in our immune system. Recall, antibodies are secreted by plasma cells.

There are 5 major classes: IgA, IgE, IgD, IgG, IgM

There are actually text books written on this stuff, thus I leave that to you in graduate school. **I will present what you need for your exam:**

1) IgG:

Most abundant (about 75%), also longest half-life

Only immunoglobulin that can cross the placenta... protects newborn against infections... confers what is called passive immunity.

Chapter 20 - Cell players - Circulatory and Immune System

Efficient on turning on the “complement” protein system, which aids the immune system. The complement protein system is actually over 30 blood proteins that take part in inflammation, and even phagocytosis.

2) **I_gM:**

Also effective in activating complement system

Together with I_gD, it is found in surface of white blood cells (I_gD and I_gM work together to bind antigens to B-cells)

First class to be secreted in a primary response

3) **I_gA:**

Found in breast milk, tears, saliva, vaginal fluid, and mucous. Confers passive immunity to the nursing infant.

4) **I_gD:**

Found on the surface of B-cells and is involved with cell differentiation and B-cell activation

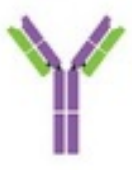
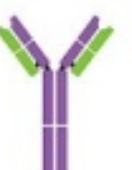
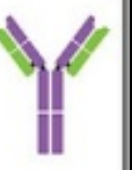
5) **I_gE:**

Triggers mast cells and basophils to release histamine in allergic reactions.

Leukotrienes, and heparin also have their release triggered

Chapter 20 - Cell players - Circulatory and Immune System

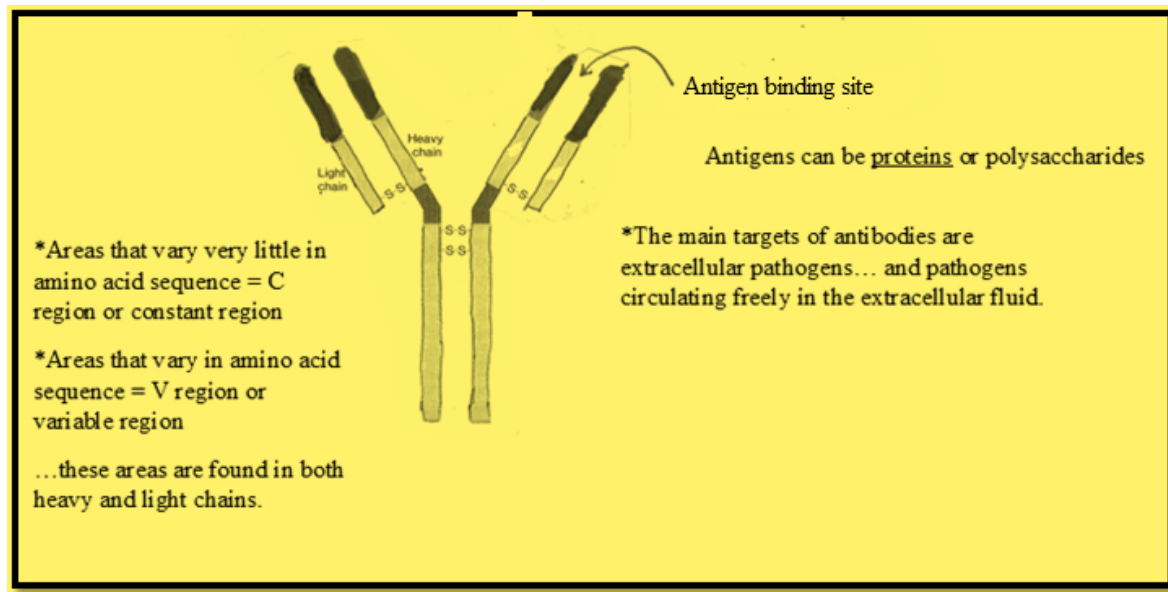
These 5 classes are sometimes called **isotypes** by immunologists

The Five Immunoglobulin (Ig) Classes					
	IgM pentamer	IgG monomer	Secretory IgA dimer	IgE monomer	IgD monomer
					
Heavy chains	μ	γ	α	ϵ	δ
Number of antigen binding sites	10	2	4	2	2
Molecular weight (Daltons)	900,000	150,000	385,000	200,000	180,000
Percentage of total antibody in serum	6%	80%	13%	0.002%	1%
Crosses placenta	no	yes	no	no	no
Fixes complement	yes	yes	no	no	no
Fc binds to		phagocytes		mast cells and basophils	
Function	Main antibody of primary responses, best at fixing complement; the monomer form of IgM serves as the B cell receptor	Main blood antibody of secondary responses, neutralizes toxins, opsonization	Secreted into mucus, tears, saliva, colostrum	Antibody of allergy and antiparasitic activity	B cell receptor
By OpenStax College [CC BY 3.0 (http://creativecommons.org/licenses/by/3.0/)], via Wikimedia Commons					

★ Just know the functions, no big details needed.

Chapter 20 - Cell players - Circulatory and Immune System

Check out the structure: 2 light chains and 2 heavy chains



Disulfide bonds:

- Link heavy chains together

★ No Antibody-Pathogen binding can occur once the pathogen or toxin is hidden in the host cell.

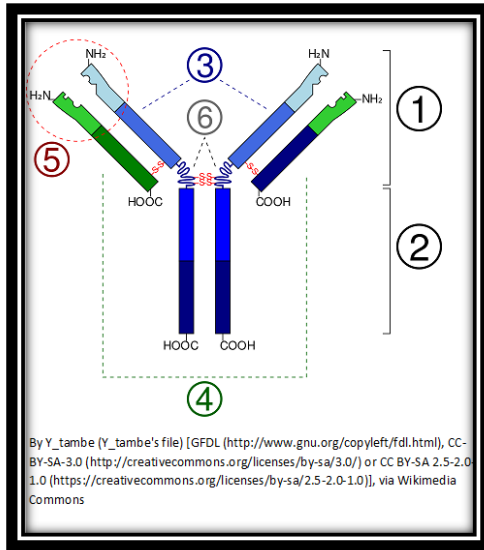
- Link heavy and light chains together

Antibodies can “tag” an antigen for destruction by the phagocytes like neutrophils or macrophages, or perhaps the complement protein attack team.

Antibodies might bind to the surface protein of an antigen and directly present this structure to a cell such as a macrophage. This “coating” the antigen with antibodies or even complement proteins is called opsonization.

An **epitope** or **antigenic determinant** is a small area that is on an antigen, it is here that an antigen receptor or antibody can bind.

Chapter 20 - Cell players - Circulatory and Immune System



MHC or Major Histocompatibility Complex

Are proteins that reside on the cell surface of most cells... but **not** red blood cells.

They are important for reactions that involve immune cells, particularly in antigen presentation to T-cells.

We divide these proteins into two subdivisions:

Class I Proteins: all cells except erythrocytes (8-12 amino acids in length)

Class II Proteins: macrophages, B-lymphocytes, and dendritic cells; cells that are an antigen-presenting cell to the helper T-cell line (13-25 amino acids in length)

What happens is this:

A pathogen is captured by a cell and broken into many fragments or what is termed “antigen fragments”. These fragments bind to an MHC molecule inside the cell... the class I protein forms a complex which is transported to the cell surface... this exposes the peptides to the cell exterior. This combination of MHC molecule and antigen is recognized by a T-cell. Two events can occur:

- 1) Cell is targeted for death
Or
- 2) Immune system is activated

Hopefully you see that cells are displaying the antigen with the use of these MHC molecules.

Class I: presents to cytotoxic T cells

Class II: presents to cytotoxic T-cells and helper T-cells

Essentially this helps lymphocytes to recognize an antigen.

Chapter 20 - Cell players - Circulatory and Immune System

Immunization

Active Immunity: two scenarios occur

- a) You produce antibodies naturally after an infection (natural)
- b) Vaccination: a vaccine is administered which is able to elicit a protective immune response

★ A vaccination gives artificially acquired active immunity

...thus it can be natural (acquired by infection) or be deliberate (acquired by vaccination).

Passive Immunity: two scenarios occur

- a) Antibody transfer from one person to another. A mother, for example, transfers antibodies to infant through breast milk or to fetus through the placenta
- b) Administration of serum or immunoglobins to people with weak immune systems.

★ Passive immunization differs from active immunization in that it does not rely on the host's immune system to take charge, but results in the immediate availability of antibodies that can be used to defend us against a pathogen. If you are bitten by a snake that is poisonous, you are given an antivenin (artificially acquired), and this antivenin contains the antibodies needed to neutralize the toxins... passive... thus a great example of artificially acquired passive immunity.

Innate vs. Acquired Immunity

Innate Immunity:

You are born with it... always present and available at very short notice to protect against invaders

Components include fever, **interferon** (a protein that is made by body cells with numerous functions such as helping nearby cells resist viral infection after it has been infected)

Other elements of the innate immunity are cells like neutrophils, macrophages, and microglia in the CNS

Acquired Immunity:

More specialized than innate, and works with the protection of the innate immune system

You are born with the capacity to mount an immune response, but only when there is direct contact with the pathogen is immunity acquired. Initial contact leads to white blood cell activation and the synthesis of proteins that exhibit specific reactivity against the invader.

Autoimmune Disease

The immune system fights itself!

Lupus, Hashimoto, Sjogren's syndrome, Multiple Sclerosis, Rheumatoid Arthritis, Type I Diabetes

Chapter 20 - Cell players - Circulatory and Immune System

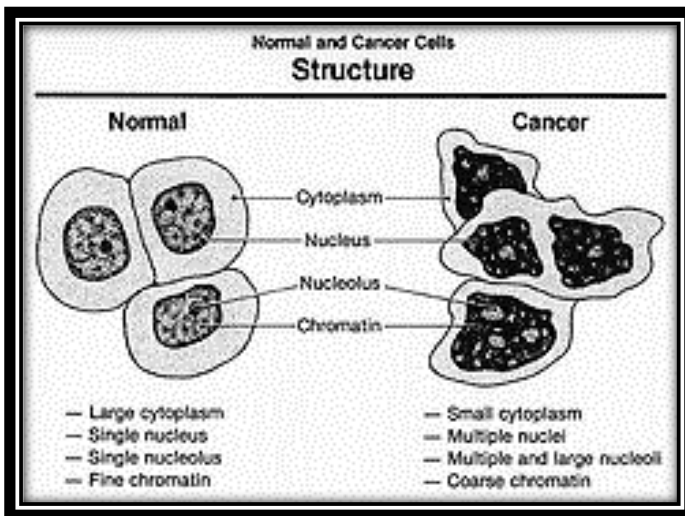
Loss of self-tolerance, for example, in multiple sclerosis, T-cells destroy myelin sheath of many neurons in the CNS.

More often in women than men!

Genetics have been linked, as well as environmental factors

In Rheumatoid arthritis, IgG molecules are “locked up” by an antibody and deposited on joint membranes. The deposit complex causes a cascade that leads to inflammation and pain.

Cancer



Chapter 20 - Cell players - Circulatory and Immune System

Cytotoxic T-cells and NK cells can destroy a cancer cell when they detect them. These lymphocytes can kill without prior MHC markers or prior sensitizations.

Neutrophils and macrophages are not normally cytotoxic to tumor cells. However, when activated by cytokines such as interferon- γ they can turn into literal “**immunological terrorists**”, yes a word that I just coined!! Macrophages may release lysosomal enzymes as well as TNF (tumor necrosis factor) a certain type of cytokine that binds to the receptor of a cell and fragments it.

Finally, I know you all have the same question... the immune system is awesome and not only protects us, but protects us from cancerous cells which can form a mass called a tumor.

Why does a cancer continue to grow, despite this immune system?

This is a long and complex question where many mechanisms operate either alone or in tandem.

Believe this or not, but some tumors that have “cell markers” suddenly shed their tumor antigens, sending the immune-fighting-cells in a different direction. This allows time for the cancer to mitotically divide and grow larger. It turns out, that as size increases, the ability of immune cells decreases. In other words, there is a finite capacity for effective tumor destruction.

Chapter 21 - Circulation

Circulation

A circulatory system must be equipped with tubes, fluid, and a muscular pump... a **heart**. This pump generates the needed **pressure** to keep the blood flowing.

Two types of circulatory systems:

Open Circulatory System

The fluid is called **hemolymph** or “**interstitial fluid**”

Hemolymph is pumped into body cavities known as **sinuses**

Arthropods and most mollusks have this type of system (Cephalopods, however have a closed system).

Recall Arthropods have:

1. Jointed appendages
2. Segmentation (head, thorax, abdomen)
3. Hard chitinous exoskeletons
4. Bilateral symmetry
5. Complete digestive tracts

They are the **most successful** organisms on Earth.

Arthropods include insects, lobsters, crayfish, spiders, and scorpions.

Arthropods have exoskeletons that are hard and do not expand; they periodically shed their exoskeleton in what is called **molting**. Enzymes partially dissolve the old exoskeleton and allow them to wiggle out of it.

Mollusks include oysters, clams, octopuses, and squids. Most secrete a hard CaCO_3 shell.

Closed Circulatory System

In a closed circulatory system, blood moves in vessels... in other words, blood is confined in continuously connected walls of a heart and vasculature.

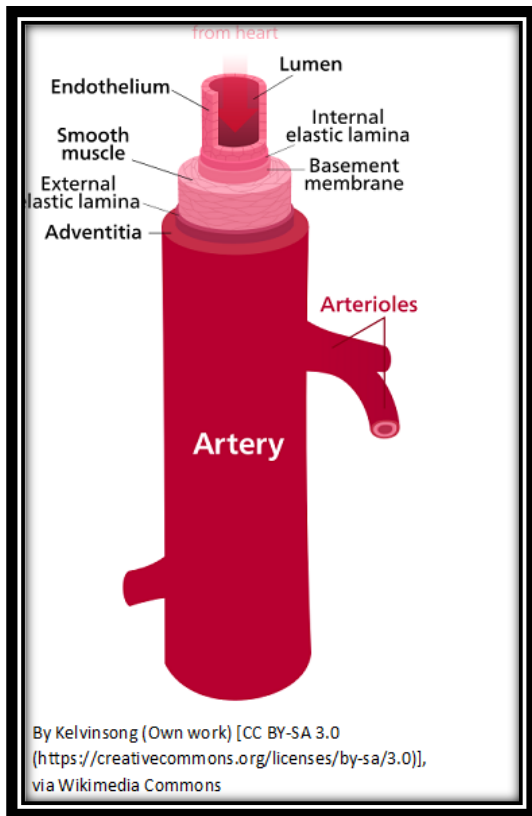
Annelids and all vertebrates have a closed circulatory system.

High blood pressures are seen here which allow for more effective O_2 delivery and nutrient delivery to body cells.

We will see a series of **vessels**... arteries, veins, and capillaries are the three main types.

Chapter 21 - Circulation

Arteries:



Usually high in O_2 , blood is under high pressure

Carry blood away from the heart

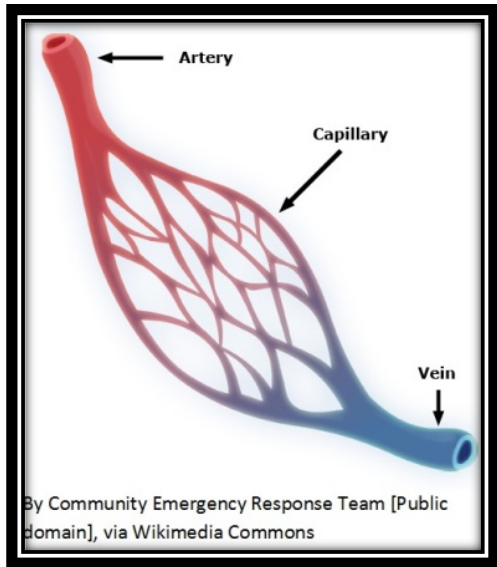
Strong and elastic... 3 distinct layers with **thick** walls

They get progressively smaller and give rise to the **arterioles**. Arterioles will convey blood to the capillaries; also have three layers.

★ The resistance is highest in the arterioles than in any part of the systemic circulation. Resistance is vital to blood flow regulation. Blood is pumped under very high pressure... and eventually decreases to almost 0 mmHg when it reaches the right atria of the heart. Their large diameters offer very little resistance to flow... thus very little drop in blood pressure.

Chapter 21 - Circulation

Capillaries:



Distributed throughout all body tissues

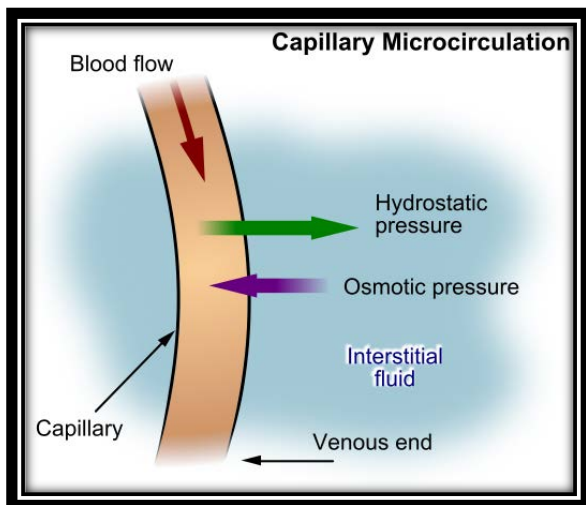
Smallest blood vessels; single layer of squamous epithelium

★ Speed of blood is slowest

Thin walls allow for substance exchange (i.e. O_2 and nutrients... **diffusion** being the most important means of transfer).

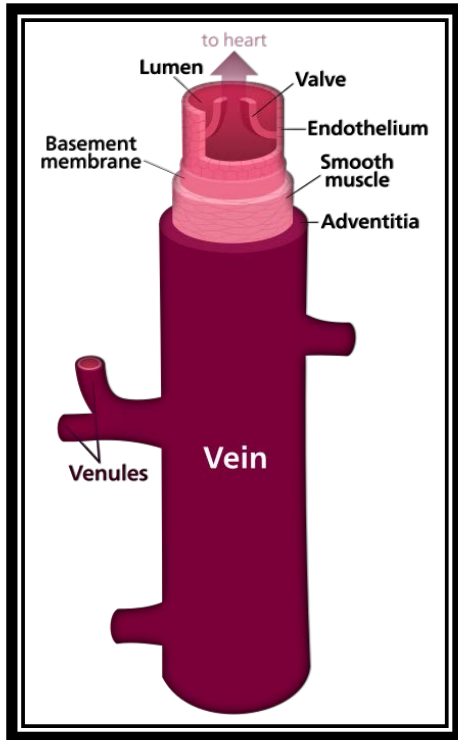
★ Largest cross-sectional area than in any part to circulatory system.

Capillaries converge into what is called a **venule**... which merge to form veins.



Veins:

Chapter 21 - Circulation



High in CO₂ generally, three layers but have thinner walls and less smooth muscle and less elasticity than arteries.

Carry blood to the heart.

Many veins have **valves**

Blood pressure is lowest here

These valves prevent backward blood flow, while pressure from muscle contractions helps to move the blood through veins toward the heart.

Normally, more fluid leaves the capillaries than returns to them, thus any excess is collected and returned to the venous circulation by the lymphatic vessels.

Number of Heart Chambers for Organisms

Let us examine the heart:

1. Mammals (man) and birds: 4 chambered heart
2. Reptiles: 3 chambered heart (crocodilians have 4 though!!), Alligators too!
3. Amphibians: 3 chambered heart
4. Fish: 2 chambered heart

A “must know” for the DAT exam.

Chapter 21 - Circulation

You need to know a few things about the heart circuit... let us review:

Terms

Atria: Upper Chamber

Ventricle: Lower Chamber

Superior Vena Cava: brings blood low in O_2 to right atria from upper body

Inferior Vena Cava: brings blood low in O_2 to right atria from lower body

Tricuspid valve: Between right atria and right ventricle

Mitral Valve (Bicuspid): Between left atria and left ventricle

Semilunar valves (Pulmonary valve and Aortic):

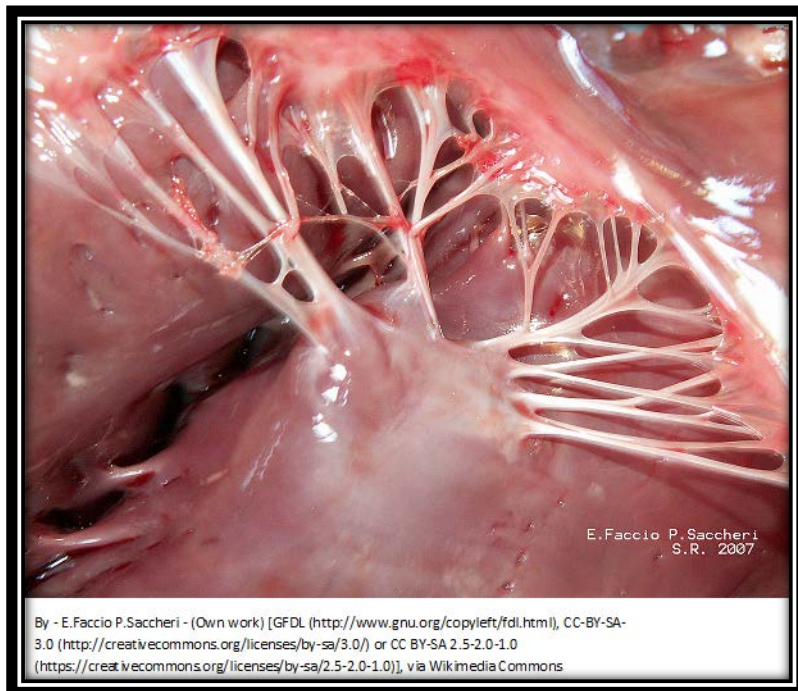
- Aortic valve separates left ventricle and aorta (Largest Artery). Keeps blood from flowing backward!!
- Pulmonary valve separates right ventricle from pulmonary artery

Lub-Dup: heart sounds due to closing of the valves.

- Lub: 1st sound; AV valves close
- Dup: 2nd sound; Semilunar valves close

Papillary Muscles: muscles in the ventricles that help to stabilize heart valves

Chordae Tendineae: fibrous “strings” attached to the cusps on the ventricular side, originating from the papillary muscles.



Chapter 21 - Circulation

Systolic Pressure: Arterial blood pressure when ventricles contract (normal $\approx$ 120 mmHg)

Diastolic Pressure: Arterial blood pressure when ventricles relax (normal $\approx$ 80 mmHg)

★ **Cardiac Muscle:** Usually mononucleated, striated, loads of mitochondria

Intercalated discs: transverse bands that separate adjacent ends in cardiac muscle fibers; essentially, they hold cardiac adjacent cells together... they have a low resistance; hence impulses can move rapidly!

SA Node... Pacemaker... found in Right Atrium... The cells can excite themselves to initiate impulses!! Generates electrical impulses analogous to nerve cells.

Heart's Electrical System

Involves:

SA node, AV node, His-Purkinje system

Details are not important for the DAT exam, but understand the following:

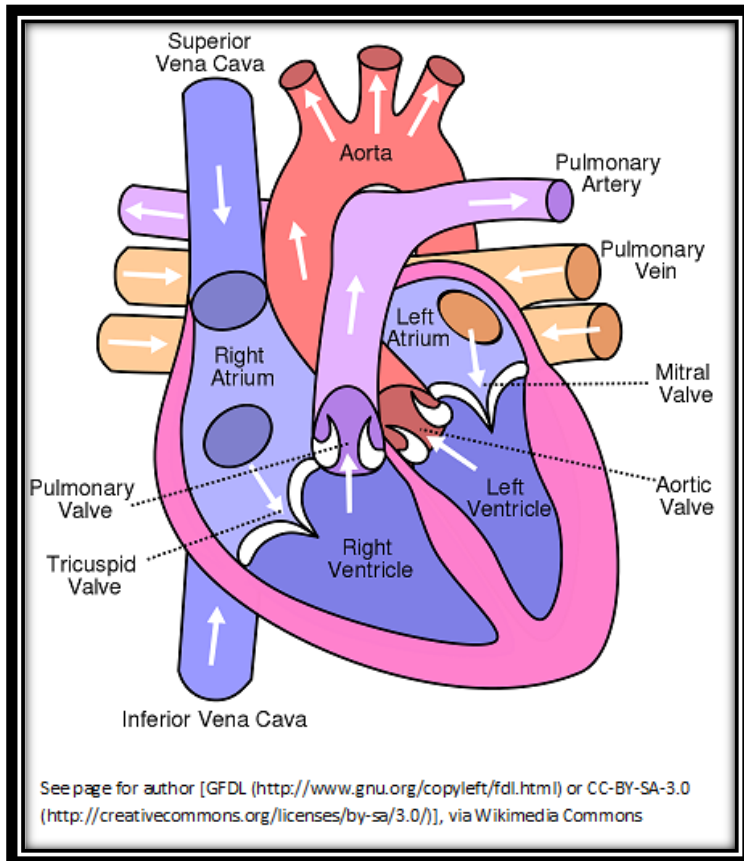
1. SA Nodes send out an impulse; both atria contract

2. From SA $\longrightarrow$ AV node ... there is a slight delay at the AV node to allow time for Atrial Systole before the ventricles begin to contract. Once the impulses reach the His bundle and Purkinje fibers the ventricles contract.
Thus... SA node $\longrightarrow$ AV node $\longrightarrow$ Bundle of His and Purkinje Fibers is our path!!

Chapter 21 - Circulation

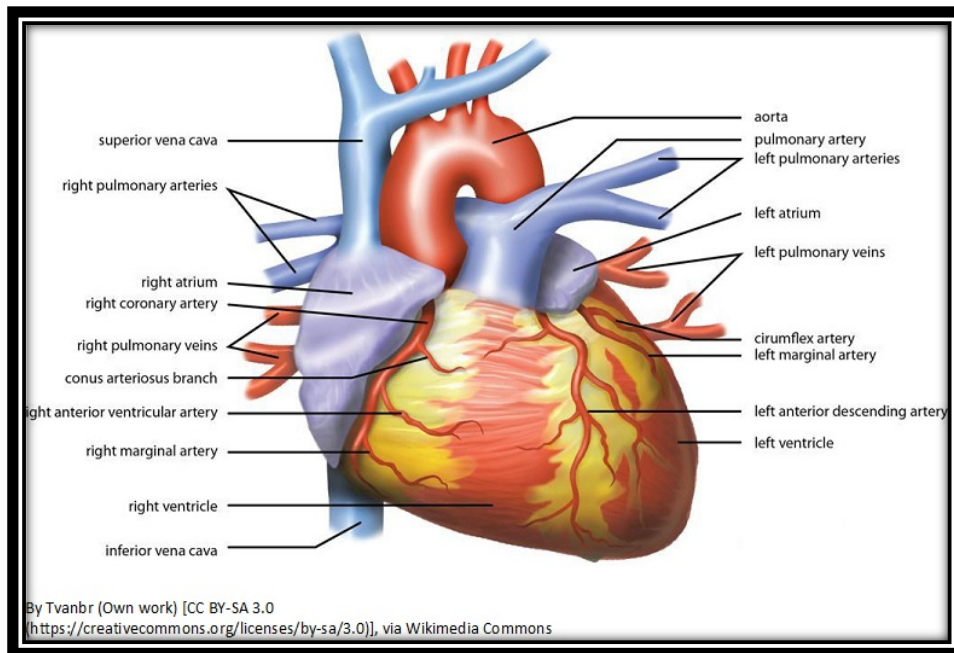
The Heart

Now let us look at the heart:



Aorta is the largest artery in the body. Arising from this artery are the coronary arteries, two in number, which supply the heart with blood.

Chapter 21 - Circulation



Let us trace a drop of blood in this circuit.

1. Blood from the upper body and lower body is low in O_2 ... high in CO_2 , is brought to the right atria via the Superior and Inferior Vena Cava respectively.
2. Right Atria to the Right Ventricle through the open Tricuspid Valve
3. From the Right Ventricle, blood is propelled to the Right and Left Pulmonary Arteries, which are low in O_2 , and taken to the lungs.
4. Blood is oxygenated within the lung capillaries and transported to the Left Atrium, via the Pulmonary Veins (two from each lung).
5. Blood now goes from the Left Atrium to the Left Ventricle. Oxygenated blood now leaves the left ventricle through the Ascending Aorta.

(I didn't confuse this up with all the valves closing, but this should be fine for the DAT. In physiology we go into this in a bit more detail).

- ★ In the lungs O_2 and CO_2 are exchanged in tiny sacs called **alveoli**. Those alveoli are the functional units of the respiratory system. O_2 can diffuse through the alveolar walls and attach to the hemoglobin of erythrocytes (red blood cells).
- ★ Gas exchange occurs by **Passive Diffusion**.

For the DAT: Make sure you know that arteries are high in O_2 , veins are low in O_2 , but not for the Pulmonary artery and vein!!

Pathologies

Risk factors for cardiovascular pathologies include:

Chapter 21 - Circulation

- a) High blood pressure
- b) Obesity
- c) Smoking
- d) Lack of Exercise
- e) High Cholesterol
- f) Genetics
- g) Age

In **Atherosclerosis**: we lose elasticity of arteries and they thicken and lipids build up. This can lead to further problems such as a heart attack.

In **Arrhythmias**: we see irregular or abnormal heart rhythms

- ❖ **Bradycardia**: decrease heart rate
- ❖ **Tachycardia**: increase heart rate

In **Hypertension**: high blood pressure... we see an increase force at which blood is pumped against arterial wall. This can lead to damage of the blood vessel, and can ultimately lead to death.

Chapter 22 - Integumentary System (The Skin)

Integumentary System (The Skin)

The skin, or integument is the **largest organ** of the human body. The integument also includes the associated structures such as nails, hair, and glands.

Thickest skin: palms of hands and soles of feet (exposed areas to wear and tear, and do not have hair)

Thinnest skin: external genitalia, eyelids, and tympanum of the ear

Primary functions:

- 1) First line of defense: protects us from injury and disease
- 2) Prevents loss of water (keratin is involved with waterproofing the skin)
- 3) Regulates temperature: think sweating!!
- 4) Stimuli Reception: sensory receptors perceive pain, touch, pressure, etc.
- 5) Vitamin D production: however, some sunlight is needed

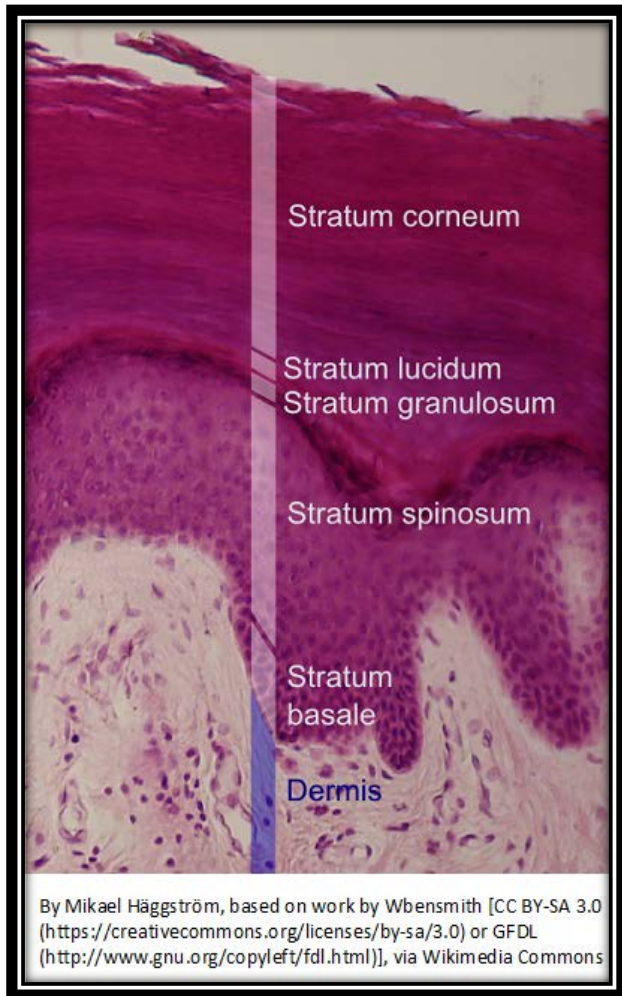
Layers include:

- a) **Epidermis** (derived from ectoderm)
- b) **Dermis** (derived from mesoderm)
- c) **Hypodermis** (subcutaneous fat layer)

The hypodermis, a loose connective tissue can vary in the amount of fat present. It is **not** actually part of the skin, but a superficial fascia deep to the skin.

Chapter 22 - Integumentary System (The Skin)

Epidermis



The epidermis consists of what is called stratified squamous keratinized epithelium.

★ **No blood vessels are found in the epidermis!**

All but the deepest layers are made of dead cells that contain a fibrous protein called keratin.

Four cell populations will be found in the epidermis that I will brief you on:

Langerhans cells:

Antigen presenting cells, sometimes called **dendritic cells**

Similar in morphology and function to macrophages

Melanocytes:

Produce melanin pigment that gives a brown color to the skin

Protects you from skin cancer, melanin absorbs UV light

Chapter 22 - Integumentary System (The Skin)

★ Reside mainly in Stratum germinativum

Merkel cells:

Function as mechanoreceptors (a sensory receptor that responds to pressure or distortion)

Keratinocytes:

80% of the cell population of the epidermis

Produce keratin, this protein not only waterproofs the skin, but protects it from damage

Keratin is also found in turtles, claws of reptiles, nails, horns, shells, feathers, and beaks

Layers of the epidermis include:

1) Stratum corneum

Stratum Lucidum is in thick skin.

2) Stratum lucidum

3) Stratum granulosum

4) Stratum spinosum

5) Stratum basale (germinativum)

Details are not needed, but do at least know these facts:

1) Stratum corneum:

Surface layer

Surrounds layers of flattened, keratin-containing dead cells called horny cells or squames

2) Stratum germinativum:

Melanocytes and Merkel cells are here **(know this!!)**

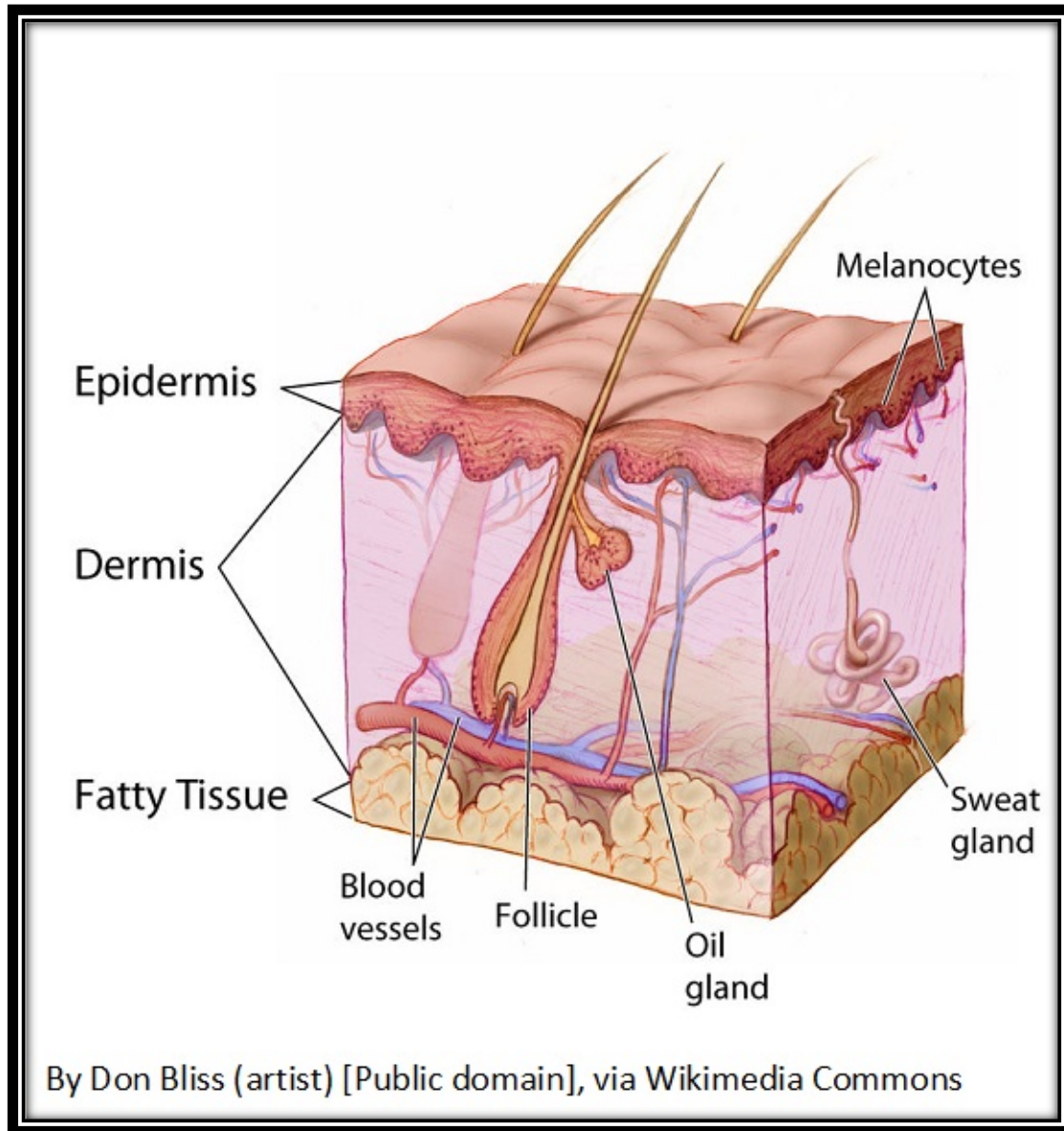
The deepest epidermal layer

Mitosis is most active- contains stem cells, keratinocytes do mitosis at night and new cells are being pushed upwards toward the surface.

Desmosomes bind the cells of this layer together. Desmosomes mechanically link the cells together and allow them to function as a single unit.

Chapter 22 - Integumentary System (The Skin)

Dermis



This connective tissue supports the epidermis and binds it to the hypodermis.

- Hair follicles
- Sweat glands
- Sebaceous (oil) glands
- Rich supply of nerves, muscles
- Derived from mesoderm, unlike the epidermis which was derived from ectoderm

★ Interestingly, sweat glands, sebaceous glands, and hair follicles are all derived from the epidermis, invade the dermis and hypodermis during embryogenesis and reside in these areas permanently.

Chapter 22 - Integumentary System (The Skin)

In the deep dermis we find:

- a) **Ruffini corpuscles:** mechanoreceptors that detect stretching and pressure
- b) **Pacinian corpuscles:** mechanoreceptors that perceive touch, pressure, and vibrations
- c) **Meissner's corpuscles:** detect light touch and sensitivity
- d) **Nociceptors:** pain perception
 - Myelinated nerve endings that branch freely in dermis!
- e) **Thermoreceptors:** heat detection (warmth and cold)

The dermis also contains:

1) Collagen:

- Most abundant fibrous protein which provides strength
- Has a triple helix
- Highly abundant in glycine
- Contains hydroxy lysine and hydroxyproline (Vitamin C hydroxylates proline & lysine)
- Every third position is occupied by glycine!

2) Elastin: fibrous protein that provides elasticity

★ As we age, collagen and elastin fibers break down and become sparser, resulting in wrinkling of the skin.

3) Extracellular Matrix: jelly-like substance that consists of polysaccharides and proteins.

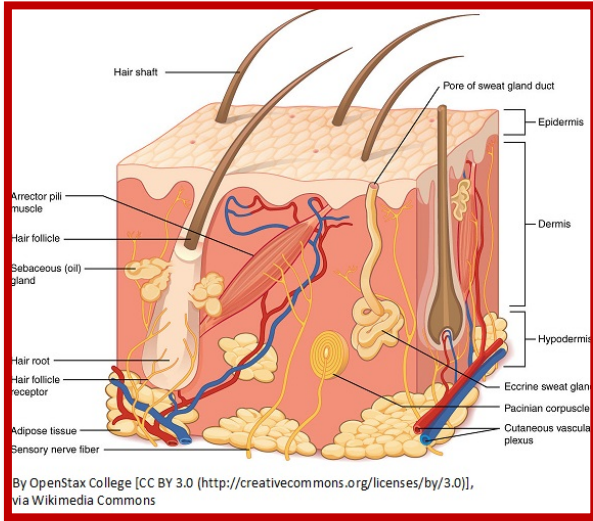
Chapter 22 - Integumentary System (The Skin)

Hypodermis

Not part of the skin

Layer of fat, but does have blood vessels

Also called subcutaneous fat layer



Tattooing

This involves the insertion of pigment into the **dermis**. Macrophages try to clean up this “inflammatory mess”, but cannot get rid of the pigment... it remains. Some macrophages do carry the dye to lymph nodes, but many remain in the dermis. Thus, as you can see you might be stuck with your lover’s name on your body for life!!

Cell Abnormalities

If there is an increase in dividing cells in the stratum basale and stratum spinosum and an accelerated cell cycle resulting in an increase in keratin-producing cells and thickening of the epidermis- this is **Psoriasis**. Lesions are common on the scalp, knees, or just about anywhere!

Benign epidermal growths caused by infection of the keratinocytes by a virus produces a **wart**.

Warts are a classic example of pathological hyperplasia (an increase in cell number).

A few terms to know:

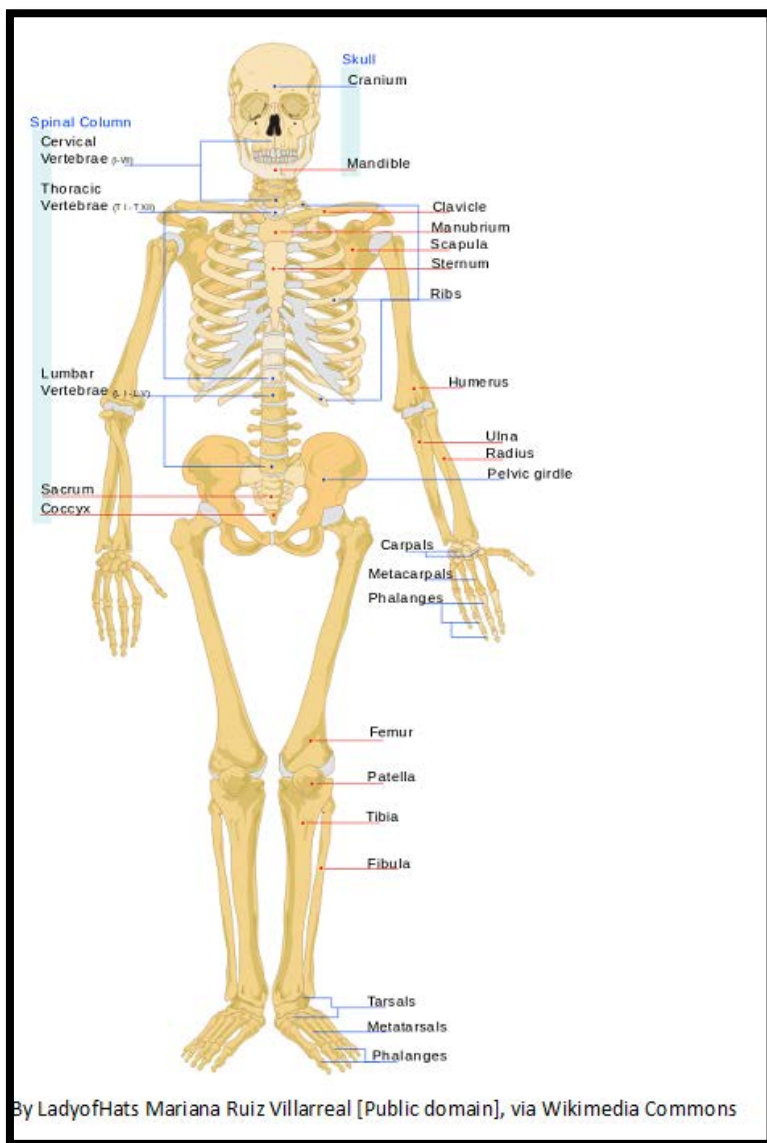
- 1) **Hyperplasia**: increase in cell number (i.e.- warts)
- 2) **Metaplasia**: conversion of one cell type to another (i.e. you smoke, you lose the cilia from your cells- ciliated cells become non- ciliated, this can be reversible)
- 3) **Dysplasia**: size, shape, and alteration of the cell components. Think of it like “pre-cancer”
- 4) **Anaplasia**: loss of cellular and organization differentiation. Think cancer. These cells vary in size and shape, we call this pleomorphism.
 - Very dark staining nuclei (hyperchromatism)
 - Tons of mitotic figures... weird, abnormal cells

Chapter 22 - Integumentary System (The Skin)

- 5) **Hypertrophy:** an increase in the cell size of a tissue or organ. Runners of marathons often have bigger hearts.
- 6) **Atrophy:** decrease in cell or organ size. Usually caused by inadequate nutrition of the cells
 - Thymus shrinks (atrophy) after puberty
 - Breasts and uterus atrophy after menopause

Chapter 23 - Bone

Bone



Bone is the most rigid of the connective tissues.

Although one of the hardest tissues in the body, it is a dynamic tissue, meaning that it is constantly changing shape to deal with the stresses placed on it.

We have 206 bones. (Enamel = hardest substance in the body).

Functions in support and protection of internal organs.

Functions in the principal reservoir for ions such as Ca^{++} , PO_4^{---} , Na^+ , and Mg^{++}

Host for the hemopoietic bone marrow which makes the blood cells.

Chapter 23 - Bone

80% of bone → cortical bone

- Dense, compact bone... outer layer covered by periosteum... think strength! This is a dense, collagenous connective tissue covering diaphysis of many bones.

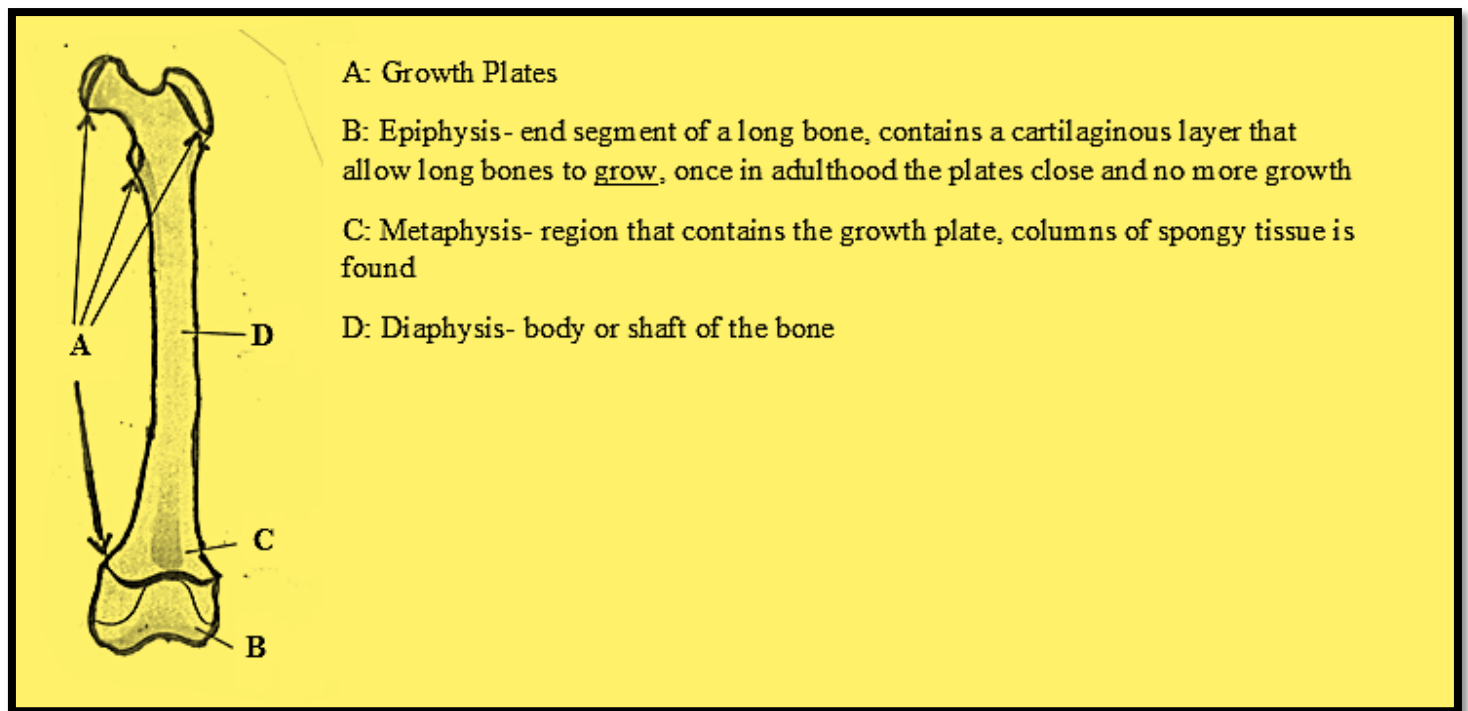
20% of bone → cancellous bone

- Spongy bone... found at the ends of long bones... highly vascular... inner layer spongy and light; provides space for the bone marrow where RBC's, WBC's, and platelets are produced.

All bones contain cortical and cancellous elements but differ in percentage.

Three terms to know:

- a) Epiphysis
- b) Metaphysis
- c) Diaphysis



Enclosed by cortical bone, bone marrow resides in a space called the **marrow cavity or medullary cavity**.

Red Marrow:

Chapter 23 - Bone

Virtually all bones at birth... tissue that makes blood and blood cells are here (hemopoietic).

At adolescence... confined to axial skeleton (skulls, ribs, vertebrae, and sternum- breastbone).

Yellow Marrow:

Fat tissue... may convert to red marrow if blood loss is severe.

Bone contains $\text{Ca}_3(\text{PO}_4)_2$... calcium phosphate as well as hydroxyapatite crystals $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ this represents the inorganic matrix. (99% of Ca^{++} in the body is stored in bone as hydroxyapatite crystals).

The organic matrix is mainly collagen, and ground substance which contains many glycoproteins.

Bottom line for the DAT: the distinguishing feature of bone is ground substance and its extracellular matrix of collagen.

A few terms:

Axial Skeleton: skull, ribs, vertebrae, sternum (breastbone)

Appendicular Skeleton: bones of pelvic and pectoral girdle like arms, legs, feet, etc.

Ligaments: dense, regular, connective tissue that connects bone to bone

Tendons: dense, regular connective tissue that connects bone to muscle

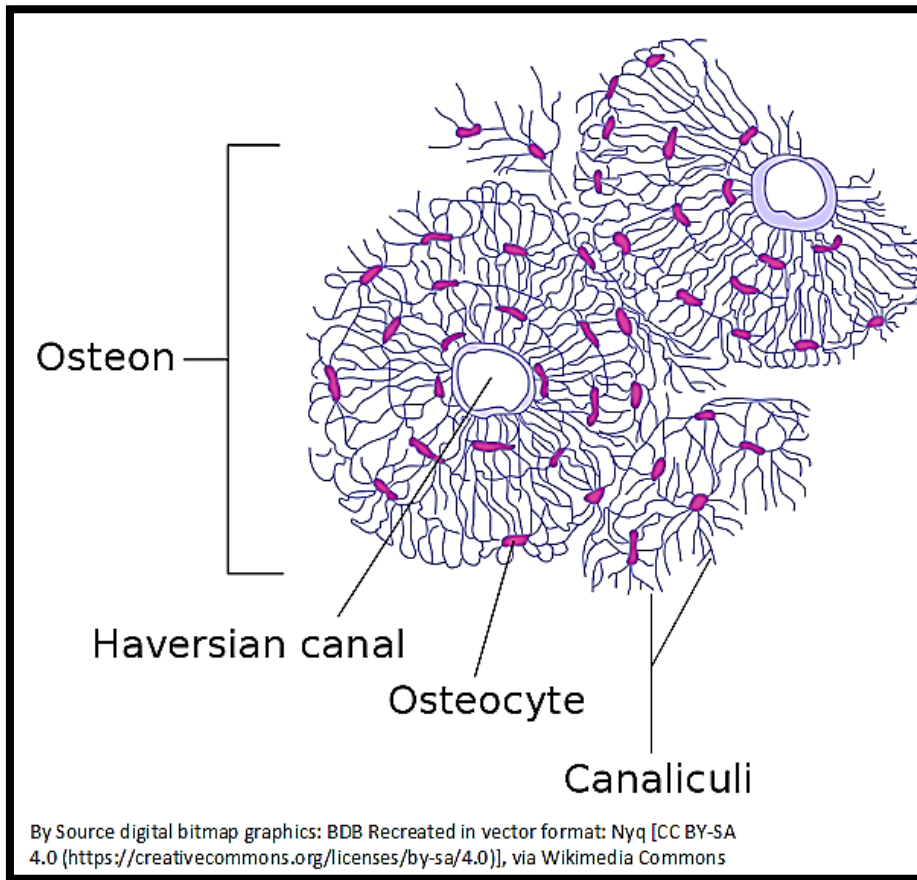
Joints: areas of contact or near contact between points

Microscopical bone can be:

- a) **Primary bone:** temporary bone usually replaced in adults- first bone to form during fetal development and during bone repair
- b) **Secondary bone:** bone usually found in adults

Chapter 23 - Bone

The Haversian System (Osteon)



A Haversian canal, with its surrounding osteocytes, lacunae, canaliculi, and concentric lamellae make up the osteon. The osteon represents the functional unit of much of compact bone.

Definitions:

- a) **Lamellae:** concentric rings of matrix surrounding Haversian canal
- b) **Canaliculi:** cavities seen within bone matrix, serve as passages for substances between the blood vessels and bone cells
- c) **Lacunae:** spaces in bone occupied by bone cells called osteocytes (one osteocyte occupies each lacuna)

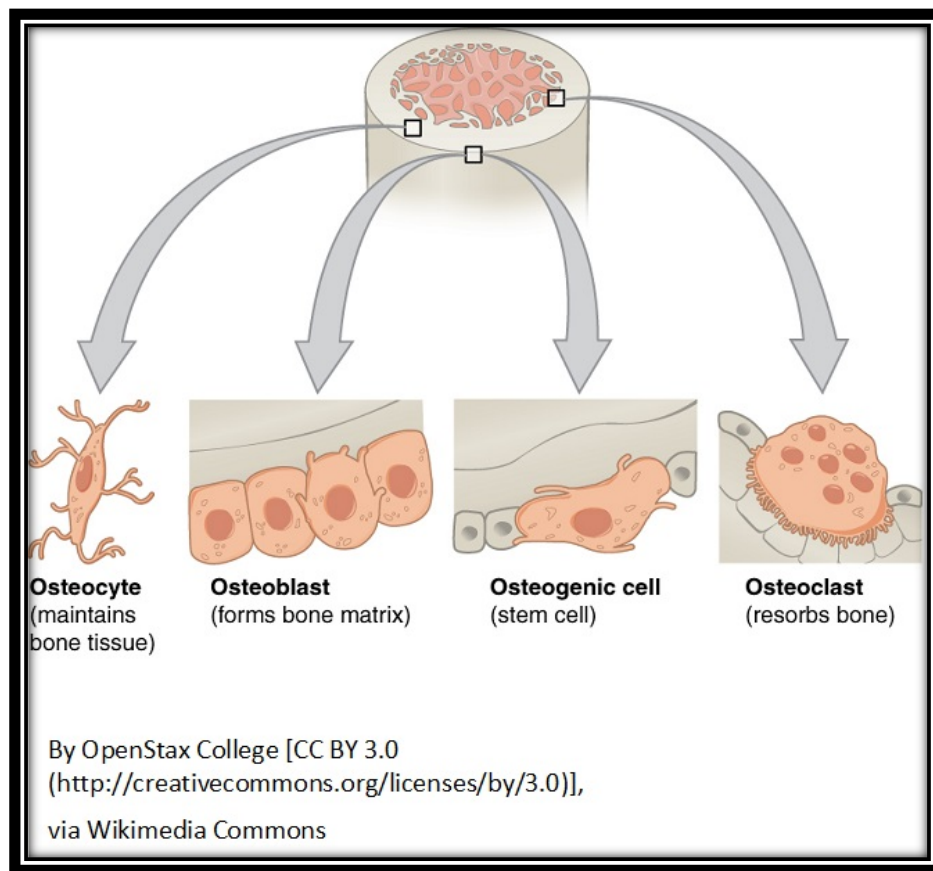
Chapter 23 - Bone

Each osteocyte occupies a space called a lacuna. Radiating from each lacuna are the small canals called canaliculi... nutrients diffuse through these canals.

The Haversian canals contain blood and lymph vessels too. They are connected by crossing canals called Volkman's canals. These canals penetrate compact bone and connect various Haversian systems with associated nerves and blood vessels.

A **scanning electron microscope** will show you a great 3D picture of all this. Stop, take the time, and have a look!

Bone Cells



1) Osteoblasts:

Found at bone surface

Mononucleated cells that build bone

Do **not** do mitosis

They make collagen (fibroblasts too!!)

They synthesize much of the organic matrix of bone, thus exhibit abundant rough ER and Golgi.

Chapter 23 - Bone

Arise from **mesenchymal cells**:

Mesenchymal stem cells give rise to a whole bunch of cells like osteoblasts, muscle cells (myocytes), cartilage cells (chondrocytes), and fat cells (adipocytes). Mesenchyme is embryonic connective tissue derived from mesoderm.

They also make many growth factors.

2) Osteoclast:

A member of the monocyte/macrophage family. They essentially break down bone (bone resorption). After they finish, they often die by apoptosis.

These multinucleated cells have abundant lysosomes and mitochondria and are very large and motile.

Occupy shallow depressions called Howship's lacunae that identify areas of bone reabsorption.

Lysosomal enzymes such as gelatinase and collagenase are secreted by these cells which degrade the bone.

3) Osteocyte:

This is simply a trapped osteoblast embedded in bone matrix and isolated in a lacuna. This cell has projections called canaliculi and can communicate with other osteocytes.

Osteocytes, osteoblasts, and osteoclasts do **not** do mitosis- **a commonly asked exam problem.**

4) Osteoprogenitor Cell:

The cell is often overlooked... it is derived from a primitive stem cell (mesenchymal) and differentiates into osteoblasts and osteocytes.

Found in the marrow, periosteum, and within the marrow cavity.

Bone Growth and Remodeling

In a young person, bone development exceeds bone breakdown. Once in adulthood, the epiphyseal plates close and bone growth has been attained, a balance occurs between growth and breakdown.

The process isn't so straightforward, but the **bottom line is this**: osteoclasts break down some bone to "excavate" the area to form an absorption cavity... Bone reabsorption stops. Osteoblasts now take over to build new bone. This process of bone breakdown (resorption) followed by bone replacement is called coupling. **Very important DAT topic to understand.**

A few bone pathologies:

- 1) **Acromegaly**: excess growth hormone causes an increase in bone deposition without normal breakdown. Bones become very thick, especially in the face.
- 2) **Osteoporosis**: a decrease in bone mass, which gets worse as estrogen levels decline. Estrogen therapy could help- bones become very fragile as osteoclastic activity exceeds bone deposition... thus making bones easy to break. ★ Not getting enough calcium may indeed contribute to the development of osteoporosis.

Chapter 23 - Bone

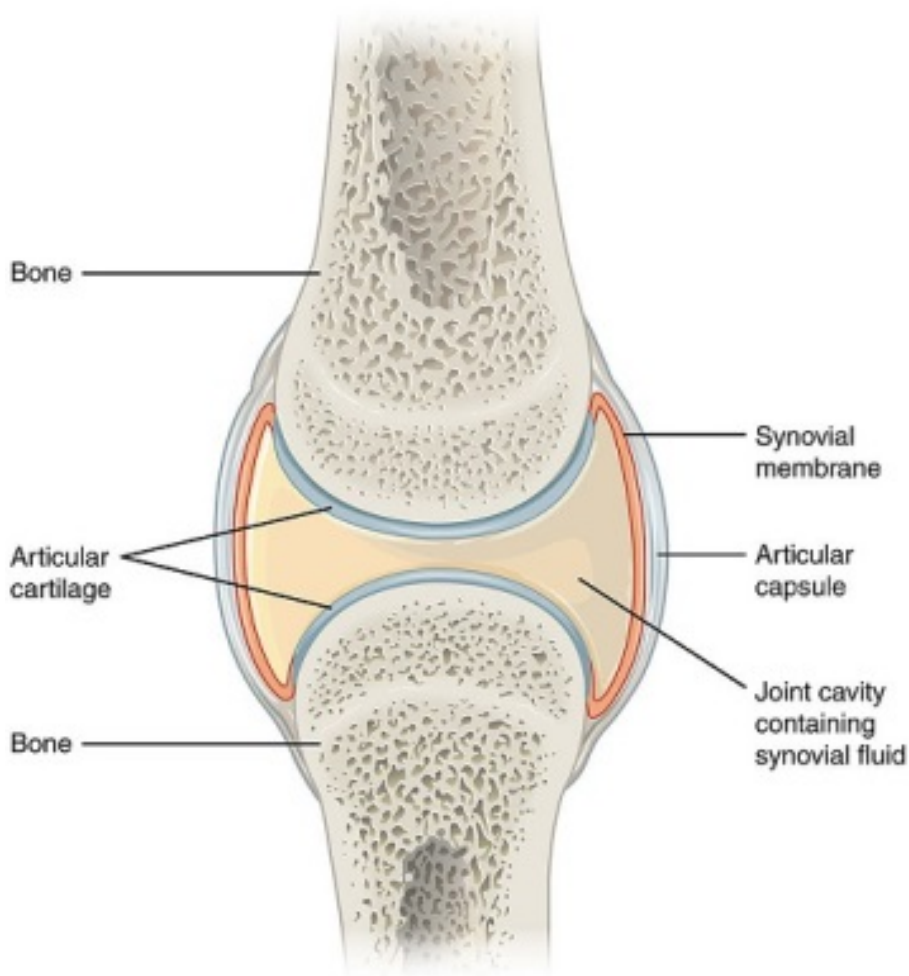
The thyroid gland and parathyroid gland are involved directly with bone.

When Ca^{++} levels decrease... parathyroid hormone is secreted. This hormone activates receptors on osteoblasts stopping them from building any more bone. Chemical factors are then produced by the osteoblast called osteoclast-stimulating factor which induce osteoclast formation to break down bone and release Ca^{++} .

The thyroid gland makes calcitonin, by decreasing or “toning down” Ca^{++} levels. How? When Ca^{++} levels increase... calcitonin activates receptors on osteoclasts, inhibiting them from breaking down bone. Osteoblastic activity occurs, and the Ca^{++} go into building bone mass.

Chapter 23 - Bone

Cartilage



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via Wikimedia Commons

Like bone, another specialized connective tissue.

Does **not** contain blood vessels, nerves, or lymphatics... but get nourishment from blood vessels of surrounding connective tissues by diffusion through the extracellular matrix.

Inorganic phase is like bone, it has hydroxyapatite.

Organic structure is very different... 80% of it is water, the other 20% collagen and proteoglycans

Cells called chondrocytes occupy small cavities called lacunae. Chondrocytes make collagen and molecules needed by the extracellular matrix.

Chapter 23 - Bone

Surrounded by a dense, fibrous connective tissue called **perichondrium**. Since it has no blood supply, it has a slow rate of mitotic activity, and if damaged, heals slowly and with difficulty.

The most abundant type of cartilage is called **hyaline**. We find it in the nose, larynx (voice box), part of the ribs, trachea, bronchi, and epiphyseal plate. Hyaline reduces friction and is a shock-absorber as well as aids in bone movement...

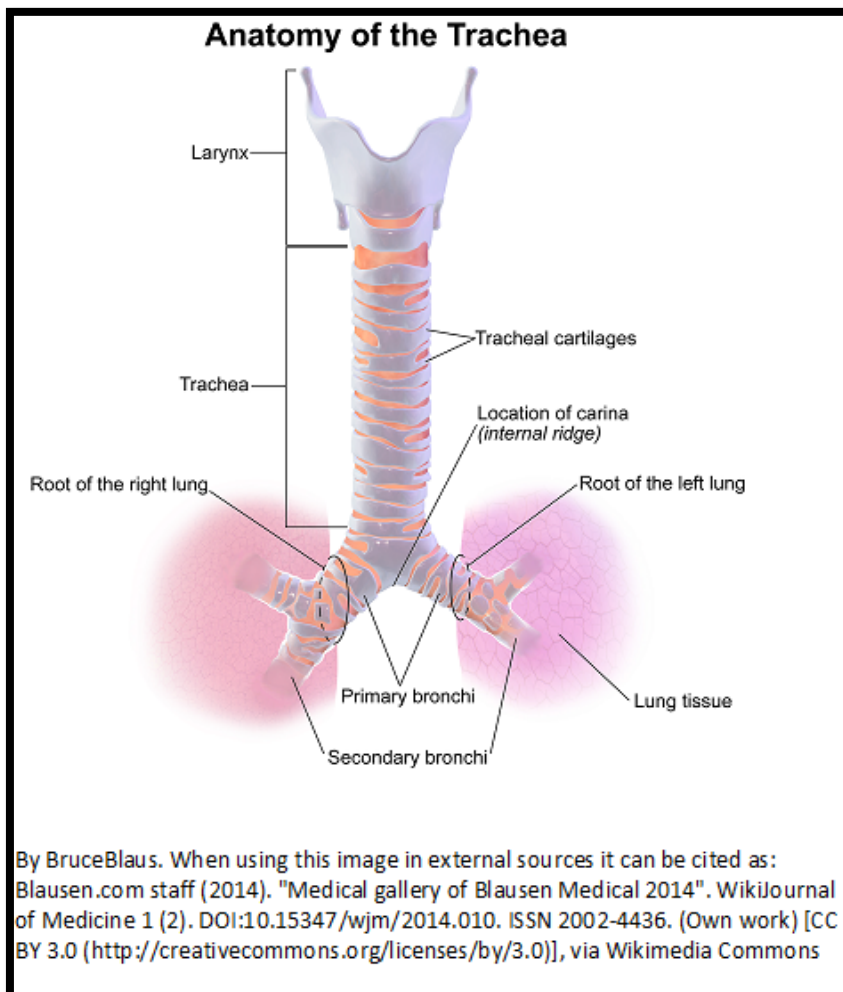
Elastic and fibrocartilage are the other types:

Elastic Cartilage: pinna of ear

Fibrocartilage: intervertebral discs... can be displaced in an injury... a “slipped disk”... can cause great pain because it compresses the lower spinal nerves

In all three forms, it is avascular!

Cartilage derives from mesenchyme and its growth depends on somatotropin (growth hormone), although not directly. We need not concern ourselves with the details here.



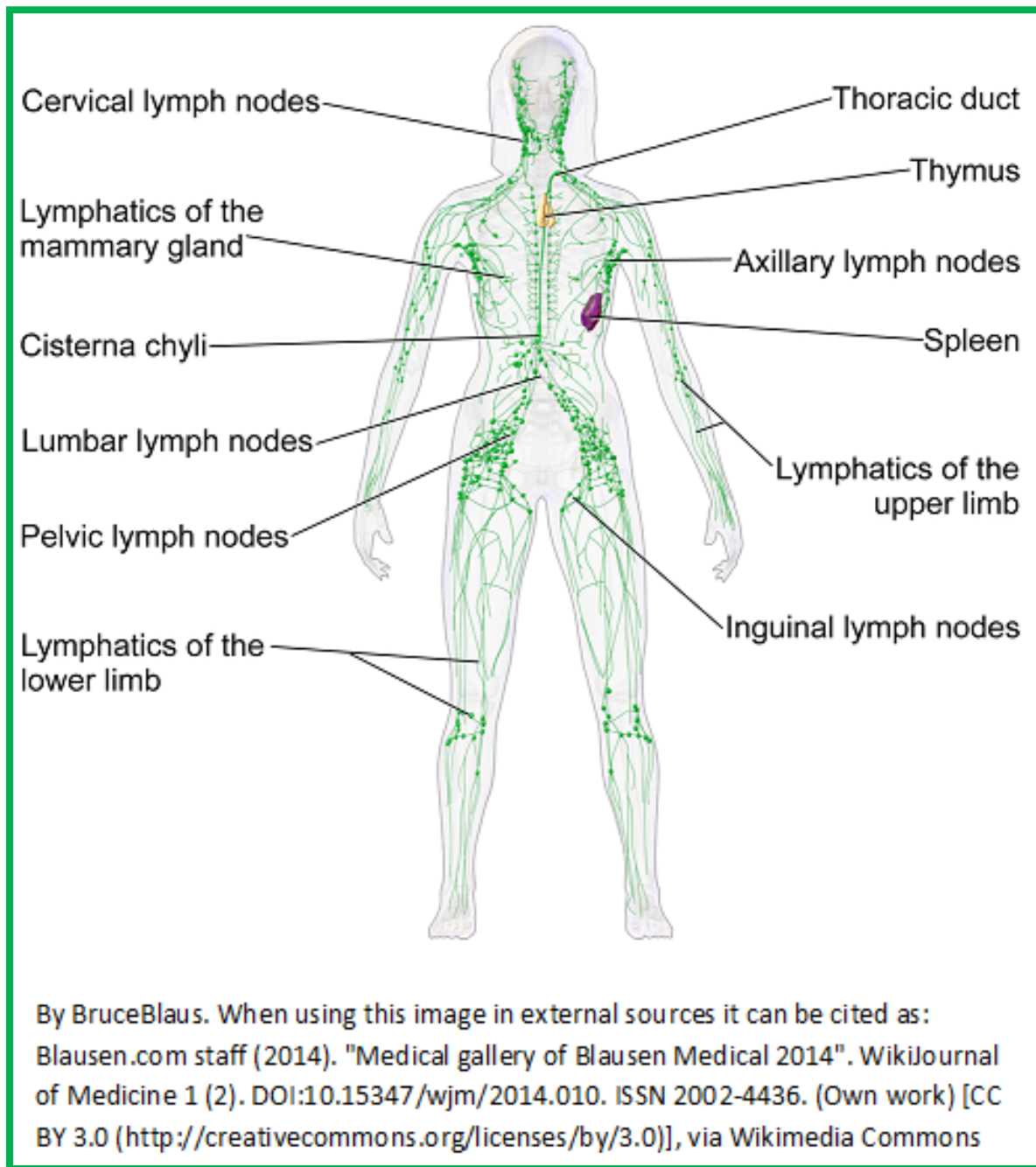
Chapter 23 - Bone

Fun Facts

- a) Arm Bones: Humerus, Ulna, Radius
- b) Leg Bones: Femur (longest and strongest), Tibia (shin bone), Fibula
- c) Foot Bones: Tarsals
- d) Hand Bones: Carpals
- e) Vertebral Bones: Cervical, Thoracic, Lumbar, Sacrum, Coccyx
- f) Coccyx = tail bone: A vestigial structure (organ) has lost most or all functioning through evolution

Chapter 24 - The Lymphatic System

The Lymphatic System



This system consists of many tubes that will collect and deliver H₂O and solutes from the interstitial fluid to the circulatory system ducts.

Lymphatic vessels are found all throughout the body **except** in areas such as: Central Nervous System, bone, cartilage, and epidermis.

This is an open system... i.e. there is no pump for circulation.

Chapter 24 - The Lymphatic System

Fluid from tissue spaces is returned to the blood by this system. This fluid (lymph) moves in only one direction- toward the heart. This fluid movement is due to contraction of the surrounding skeletal muscle.

This is an important point, since unlike the circulatory system there is no pump!!

Lymphatic vessels have walls similar to veins: **3 layers** and have **valves** which prevent lymph backflow.

Lymphatic vessels lead to specialized structures called **lymph nodes** (about an inch in diameter). Lymph nodes are filled with white blood cells. When you get sick, you might have “swollen glands” ... these are your lymph nodes that have filled-up with these immune-fighting cells called white blood cells. Hundreds are present in the human body. Sometimes a person not ill has “swollen glands”, this means it is time to see an M.D. since many cancers can cause the lymph nodes to become swollen. Primary cancers of the lymph tissues are called lymphomas.

Bottom Line: The lymphatic system brings lost protein and fluids to the blood. It also takes part in immune system surveillance.

As you can see, lymphocytes are quite spread out in the body, but very abundant in the neck, axilla, groin, and along major vessels.

Lymph nodes contain cells such as: T and B- lymphocytes, plasma cells, macrophages, and dendritic cells.

Lymphoid aggregates known as **Peyer’s Patches** are found throughout the small intestine ileum and monitor intestinal bacterial populations as well as defending us against pathogenic intestinal bacteria. Gut-associated lymphoid tissue such as Peyer’s Patches is sometimes called GALT.

Lymph is very similar to blood plasma, and it is a clear-to-white fluid (the white color is due to its lipid content when in GI tract).

The lymph nodes are the major sites of B and T cell lymphocytes. These nodes can act as “filters” for foreign particles and even malignant cells! They are also encapsulated.

B-cells make antibodies! If activated, those antibodies move out of the lymph nodes.

★ Antibodies on the move are called **immunoglobins**.

B-Lymphocytes:

Make up the **Humoral Immune System**, which functions to produce antibodies

★ Mature in the **bone marrow**!

T-Lymphocytes:

Make up the **Cell-Mediated Immune System** which functions to kill foreign or intracellular infected cells

Also involved with making cytokines

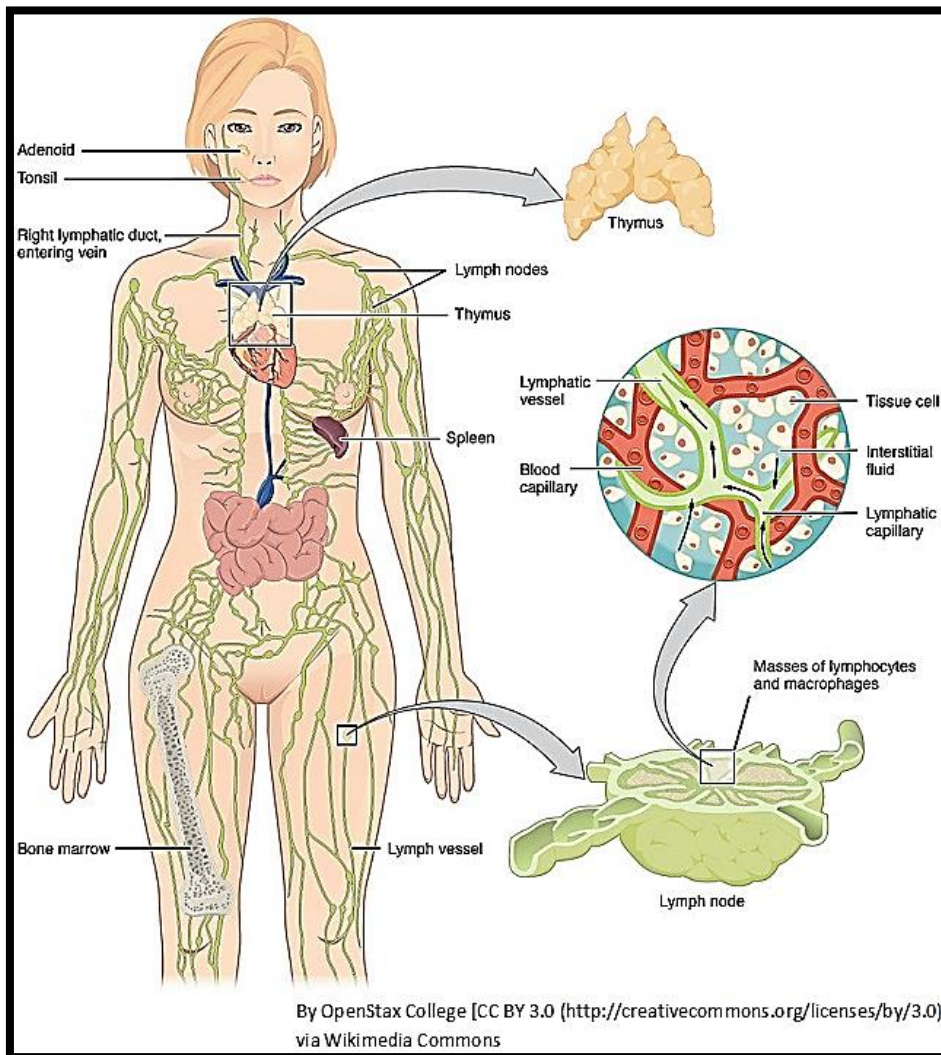
★ Mature in the **thymus**!

Chapter 24 - The Lymphatic System

The bone marrow and thymus = primary immune organs

The lymph nodes, spleen, and certain cells of respiratory & gastrointestinal tract = secondary immune organs

The Thymus



A primary lymph organ where T-cells mature

Found immediately beneath the breastbone at the level of the heart. After puberty it begins to shrink. Removal of this organ in the adult has little effect, but is vital for making immune cells in the newborn!!

Produces several “growth factors” which are proteins that stimulate the proliferation and the differentiation of the T-Lymphocytes.

Chapter 24 - The Lymphatic System

Makes the hormone thymosin which helps the T-Lymphocytes develop, among a few other thymic hormones such as thymopoietin and thymulin.

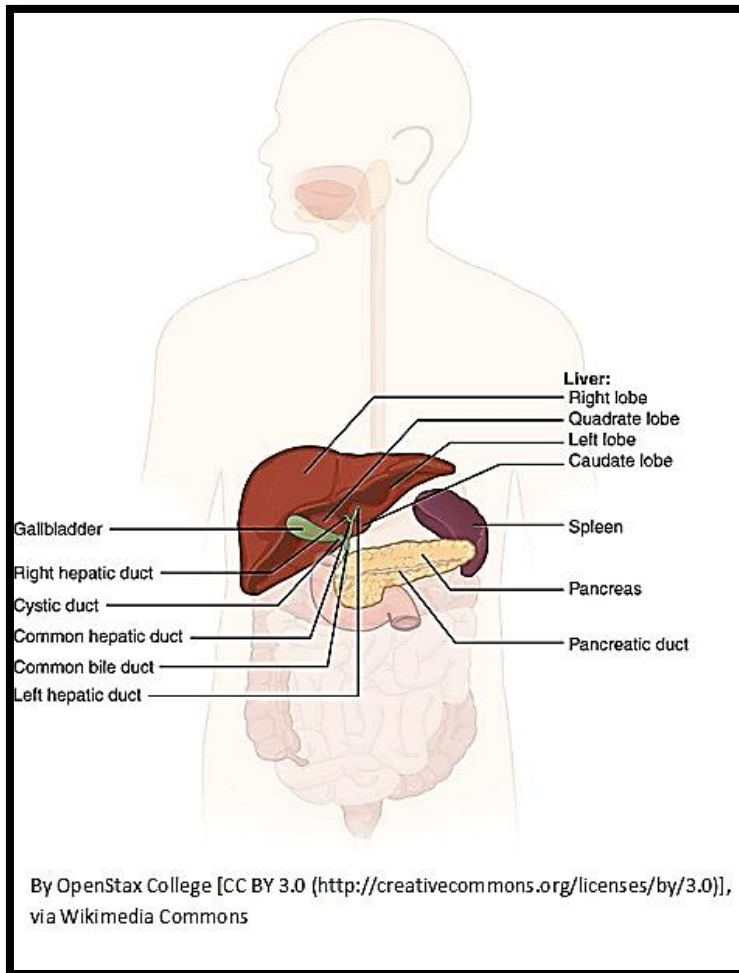
By age 75, this gland turns to fatty tissue.

Luckily for us... all or nearly all of our T-cells are made before puberty.

Did you know that congenital failure of the thymus to develop results in DiGeorge's syndrome?

T-cells can't be made; thus, a horrible fate awaits. Their cell-mediated immune system is nonfunctional and death results early in life.

The Spleen



Upper left part of the abdomen

Stores a reserve of blood, “blood reservoir”

Largest accumulation of lymph tissue in the body

Chapter 24 - The Lymphatic System

“Graveyard” of old, worn out red blood cells (they lost sialic acid residues on their surface and expose their galactose sugars! Which allows for phagocytosis.)

Produces B and T Lymphocytes

Think of this organ as a large lymph node (T-cell, B-cell, and macrophages are ready to fight off invaders!)

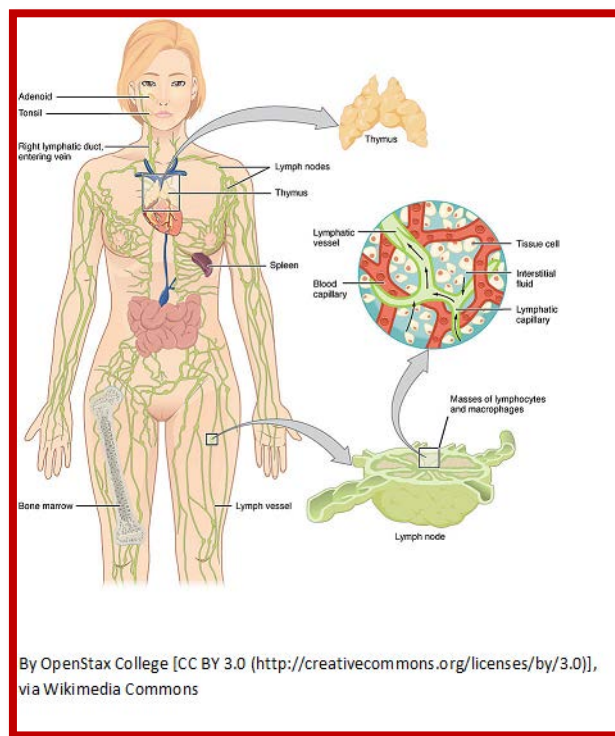
The captured red blood cells are able to recycle the iron and protein portions of hemoglobin.

Many platelets are stored here which are involved with blood clotting.

★ If you lose your spleen either by pathology or accident, the liver, lymph nodes, and bone marrow can complete its function.

Similar to Peyer’s Patches (GALT), we have BALT. This is bronchus-associated lymphatic tissue located in walls of the bronchi.

Tonsils are also aggregates to lymphoid tissue (lingual, pharyngeal, and palatine) that help guard against pathogens.



Chapter 25- The Endocrine System

The Endocrine System

This system facilitates regulation and communication of the body through chemicals called **hormones**.

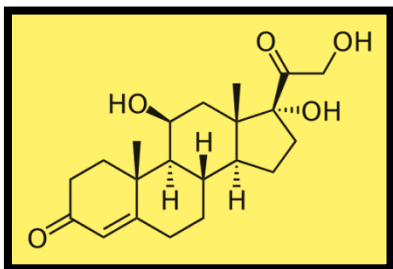
Endocrine glands secrete hormones, which travel through the body fluids such as the blood and act on specific target cells in various parts of the body to change their function.

An endocrine gland has **no ducts**; thus, their secretions are picked up and transported to their site of action by the bloodstream.

Some endocrine cells are found in body organs such as the excretory and digestive systems that will be discussed.

Three Main Types of Hormone Categories

1) Steroid hormones:

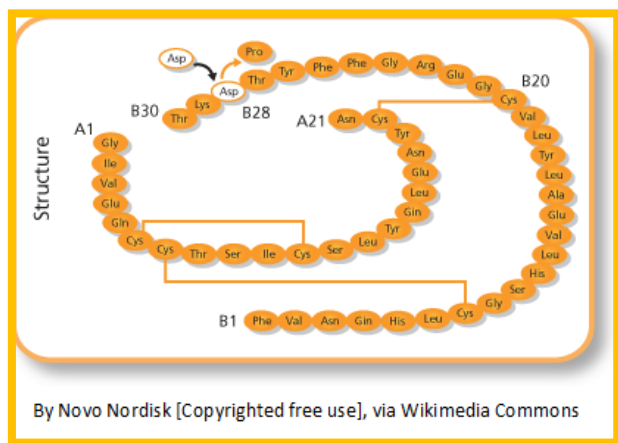


Synthesized from cholesterol (**common test question!**)

e.g. estrogen, androgens (such as testosterone), progesterone, cortisol, cortisone, aldosterone, etc.

Lipid soluble... thus can pass through the cell membrane and bind to steroid receptors (may be nuclear receptors, depending on the steroid).

2) Polypeptide hormones:



Insulin

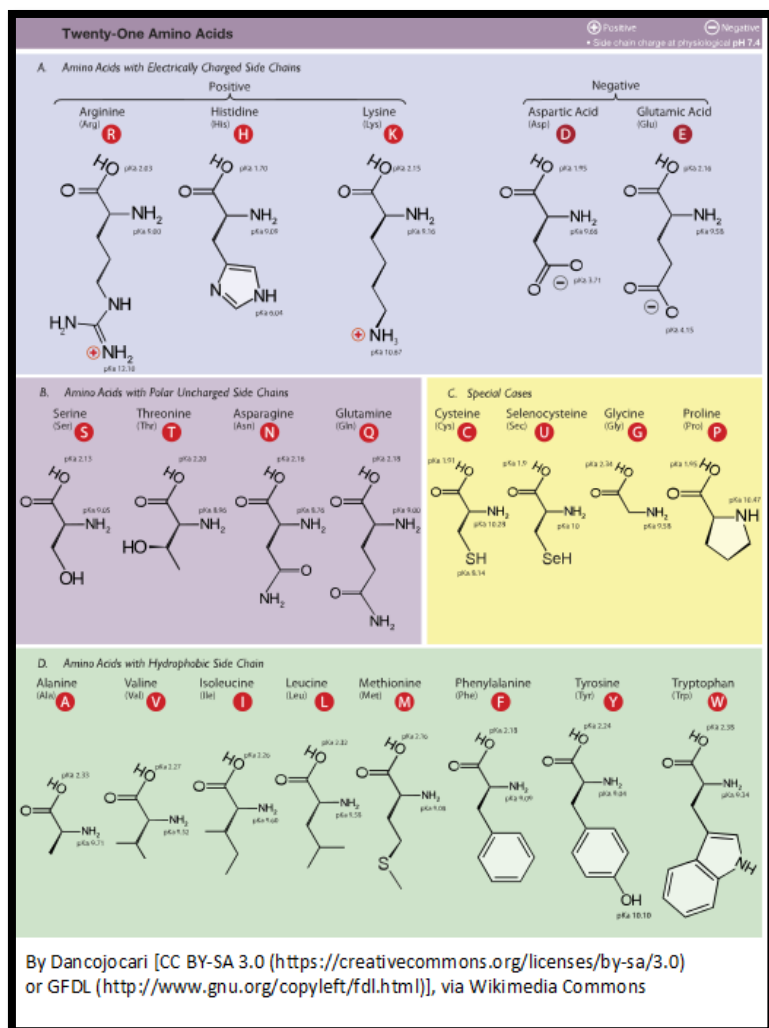
Composed of amino acids (contain C, H,O,N, and S)

Chapter 25- The Endocrine System

The molecular weight of an amino acid residue (i.e. when it joined with another amino acid, and H₂O is lost) is 110 D. Thus, to estimate the mass of a 150 amino acid protein would be 150 X 110 = 16,500 D. D stands for Dalton, the units usually used.

110 is not an exact number, but some amino acids occur more frequently than others, hence it comes damn close to most needed estimates.

Amino acids can be polar, nonpolar, aromatic, acidic, or basic when we classify them. **Let's see some examples:**



3) Amine Hormones:

Called the catecholamines

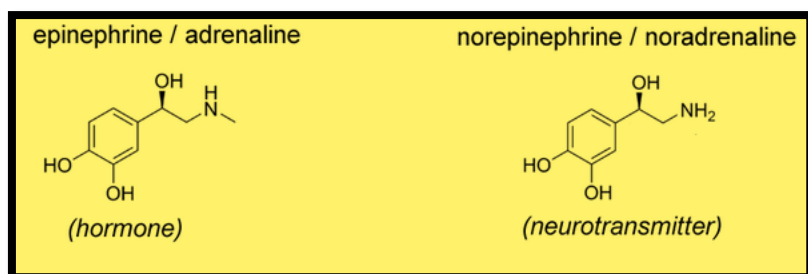
Made from the amino acid tyrosine

H₂O soluble

Chapter 25- The Endocrine System

A catechol is a benzene ring with two hydroxy groups; don't let the fancy name scare you.

A neurohormone called dopamine is also a catecholamine



Essential Concept: An endocrine gland secretes a hormone, it travels through the blood to its target site. At the site, the hormone enters the cell by passing through the cell membrane. The hormone binds to a receptor and it likely enters the nucleus. In the nucleus, activation of mRNA synthesis occurs. mRNA then can enter cytoplasm and make proteins.

The process is long, complex, and text books are written on this. Neil Campbell, PhD, has done an excellent job on the details. **For the DAT exam, I don't think diving into those details is necessary.**

Hormones are often involved what is called a "biological cascade". This simply refers to a series of chemical reactions which are initiated by a molecular binding on a receptor. The name of the game is **receptors!**

H₂O-soluble hormone: binds to cell-surface receptor protein

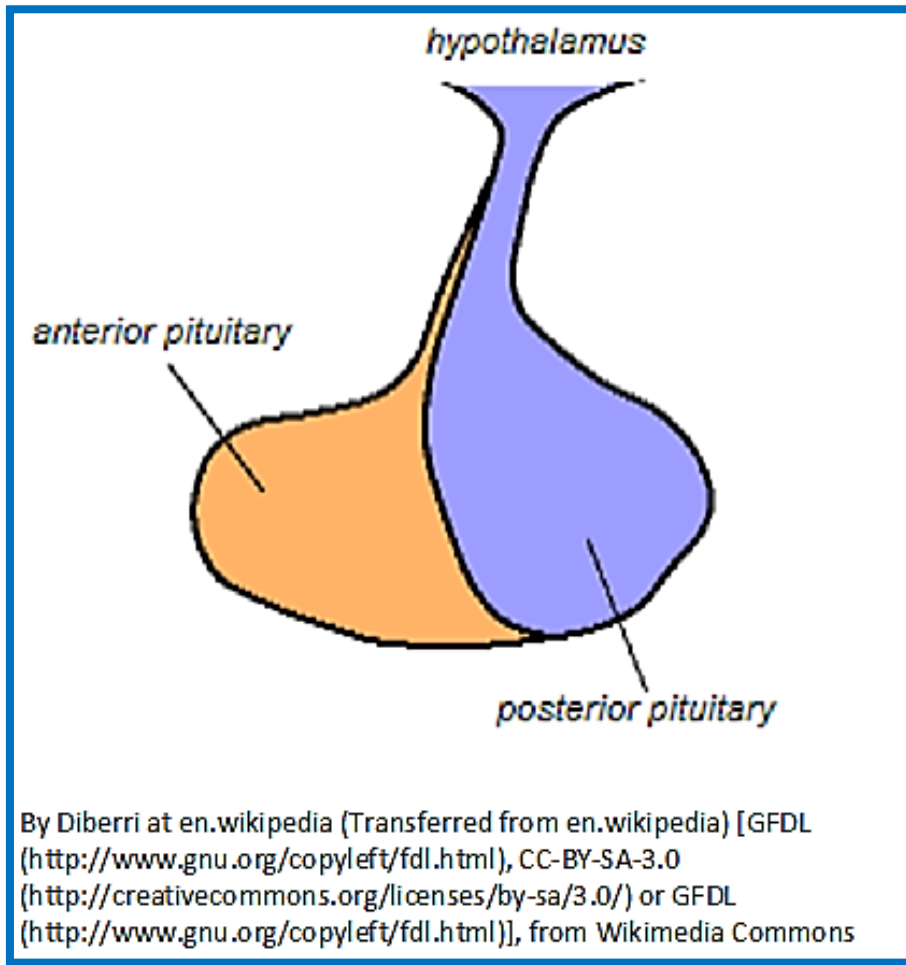
Lipid-soluble hormone: binds to an intracellular receptor in cytoplasm or in the nucleus

A very important concept, folks!!

Let us examine these endocrine glands and some of the main hormones they make:

Chapter 25- The Endocrine System

Hypothalamus



This is the LINK between the nervous and endocrine systems... this gland is located in the brain. Makes:

Oxytocin: stimulates contractions of the uterus and stimulates mammary glands to assist in milk ejection

ADH (vasopressin): this is antidiuretic hormone

Involved with H₂O retention by the kidneys. If there is severe blood loss (hemorrhage), by retaining more H₂O, this increases the blood volume, hence the blood pressure. Thus, this hormone decreases urine volume.

Careful: these two hormones will be **STORED** in the Posterior Pituitary gland, and will be subsequently released. From the hypothalamus, they travel along special axons to the posterior pituitary gland. Oxytocin stimulates milk secretion... a baby will suck more and greater stimulation occurs. This is what is called a positive feedback.

Anterior Pituitary Gland

Several hormones are secreted here... some are called **tropic hormones**... meaning they are released and stimulate other endocrine glands to release their hormones.

Chapter 25- The Endocrine System

Growth hormone (Somatotropin):

Involved with stimulation of bone growth

Increases DNA, RNA, and protein synthesis

Stimulates the liver to release IGFs... insulin growth factors which allow for bone and cartilage growth

Increases blood sugar

Abnormal amounts can result in hypersecretion... gigantism, or hyposecretion... dwarfism. Interestingly, if done before puberty human growth hormone therapy can be used for some types of dwarfism.

FSH (Follicle Stimulating Hormone):

ovarian follicle in women, spermatogenesis in males

LH (Luteinizing Hormone):

Stimulates ovulation, progesterone secretion, corpus luteum formation in women, and stimulates testosterone secretion in men.

TSH (Thyroid Stimulating Hormone):

Will stimulate the thyroid gland to make hormones and their release

ACTH (Adrenocorticotrophic Hormone):

Will stimulate the adrenal cortex to secrete glucocorticoids such as cortisol

These are all **TROPIC** hormones... **a very important concept**. They regulate the function of the other endocrine cells or glands.

Prolactin: a **non-tropic** hormone

It has various roles such as the stimulation of mammary gland growth and milk production in mammals. In fish, it is believed to control water and salt balance. Studies have shown that this hormone also has cytokine-like functions involved with the immune system, as well as acting like a growth factor. Much study is still needed on this ancient hormone with such diversified functions.

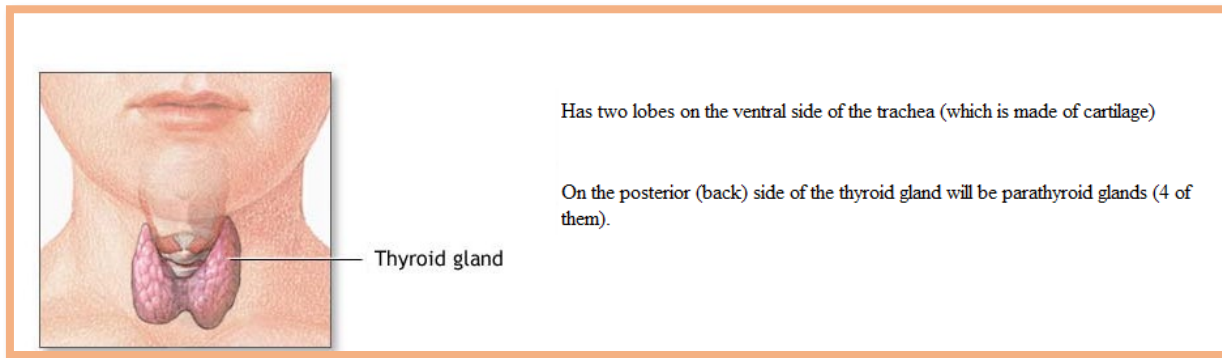
MSH (Melanocyte-Stimulating Hormone): the second **non-tropic** hormone

Regulates the function of melanocytes, involved with skin, hair, eyes, etc. Pigmentation in humans, reptiles, amphibians, and fish.

Can suppress appetite in humans by binding to receptors in the hypothalamus. Leptin, a hormone made by adipose cells also acts in appetite suppression.

Chapter 25- The Endocrine System

Thyroid Gland



Produces **thyroid hormone** which is really two hormones:

T₃ (Triiodothyronine... has 3 iodine atoms)

T₄ (Thyroxine... has 4 iodine atoms)

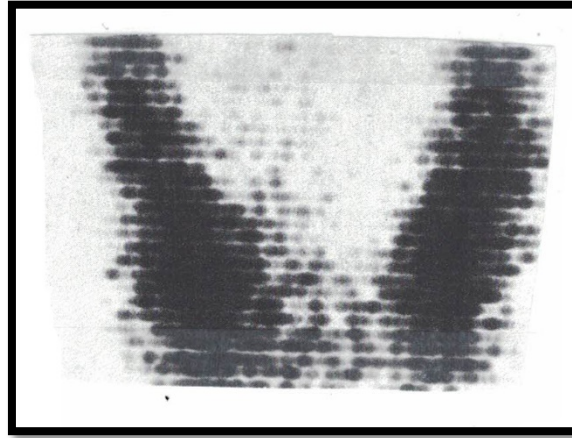
Aside Note...

- Medial: toward the midline
- Lateral: toward the side
- Proximal: closer to the origin
- Distal: further from the origin
- Ventral: pertaining to the front of a structure

T₃ & T₄ bind to the same receptor. **T₄ is more abundant.**

These hormones are involved in growth, cell differentiation, control of O₂ consumption, and the basal metabolic rate.

Chapter 25- The Endocrine System



Here is a thyroid scan a day after a patient was administered radioactive iodine which is needed for T₃ and T₄:

If too much thyroid hormone, **hyperthyroidism** results:

We would see an increase in metabolism, weight loss, profuse sweating, high blood pressure, irritability.

Grave's disease is the most common form of hyperthyroidism. This is an autoimmune disease. Protruding eyes is often seen in these patients.

If too little thyroid hormone, **hypothyroidism** results:

You are often cold, gain weight, and feel tired all the time.

★ The body tries to compensate for this by increasing the TSH from the anterior pituitary gland. It attempts to “entice” the thyroid to make more thyroid hormone. This is not good. Why? Constant TSH hormone causes the thyroid to enlarge... we call this a goiter.

Severe cases of hypothyroidism are called Myxedema. In Myxedema, we see swelling of the face, lips, eyelids, and even tongue. Heart rate and blood pressure are often quite low.

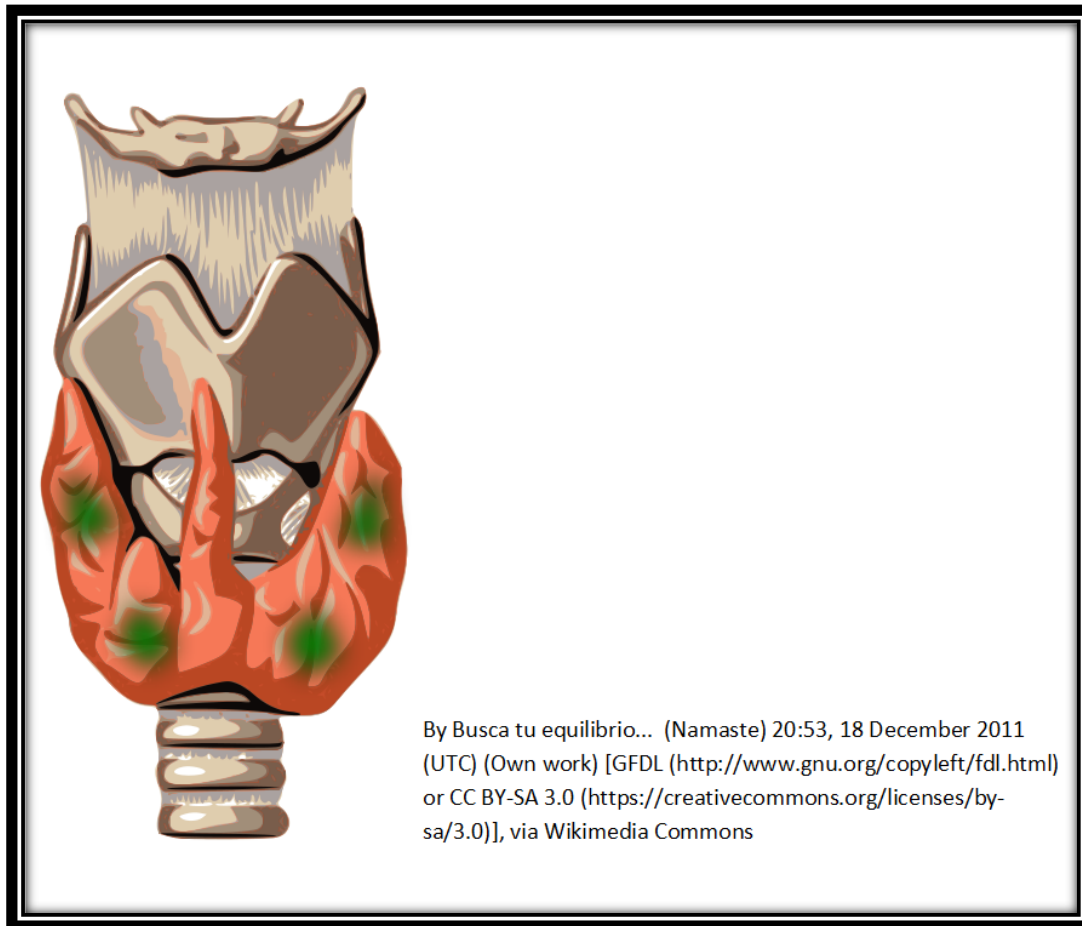
Cretinism is an extreme form of hypothyroidism in fetal life through adulthood, mental retardation and growth failure are noted.

The autoimmune disease called **Hashimoto's disease** is the most common cause of hypothyroidism, however. There is a female preference, often middle-aged women. Untreated Hashimoto's can lead to Myxedema, heart problems, goiter, and depression

Calcitonin: is another thyroid hormone which “tones” down or lowers blood calcium. Ca⁺⁺ release by the kidney is also enhanced. Calcitonin will inhibit osteoclastic activity, and will promote bone formation by osteoblasts. **(It is more complicated than this, but this is fine for what we need here).**

Chapter 25- The Endocrine System

Parathyroid Gland



4 of them, associated on the posterior surface of the thyroid gland. The hormone it makes is **PTH** or **parathyroid hormone**. It will cause an increase in blood calcium concentration.

It influences three types of organs:

- a) Bone
- b) Kidneys
- c) Intestine

In the kidneys, PTH enhances calcium reabsorption, it also induces some kidney cells to secrete enzymes that allow Vitamin D to become “activated”, which is then able to take Ca^{++} from food in the intestines. This hormone also indirectly stimulates osteoclast activity.

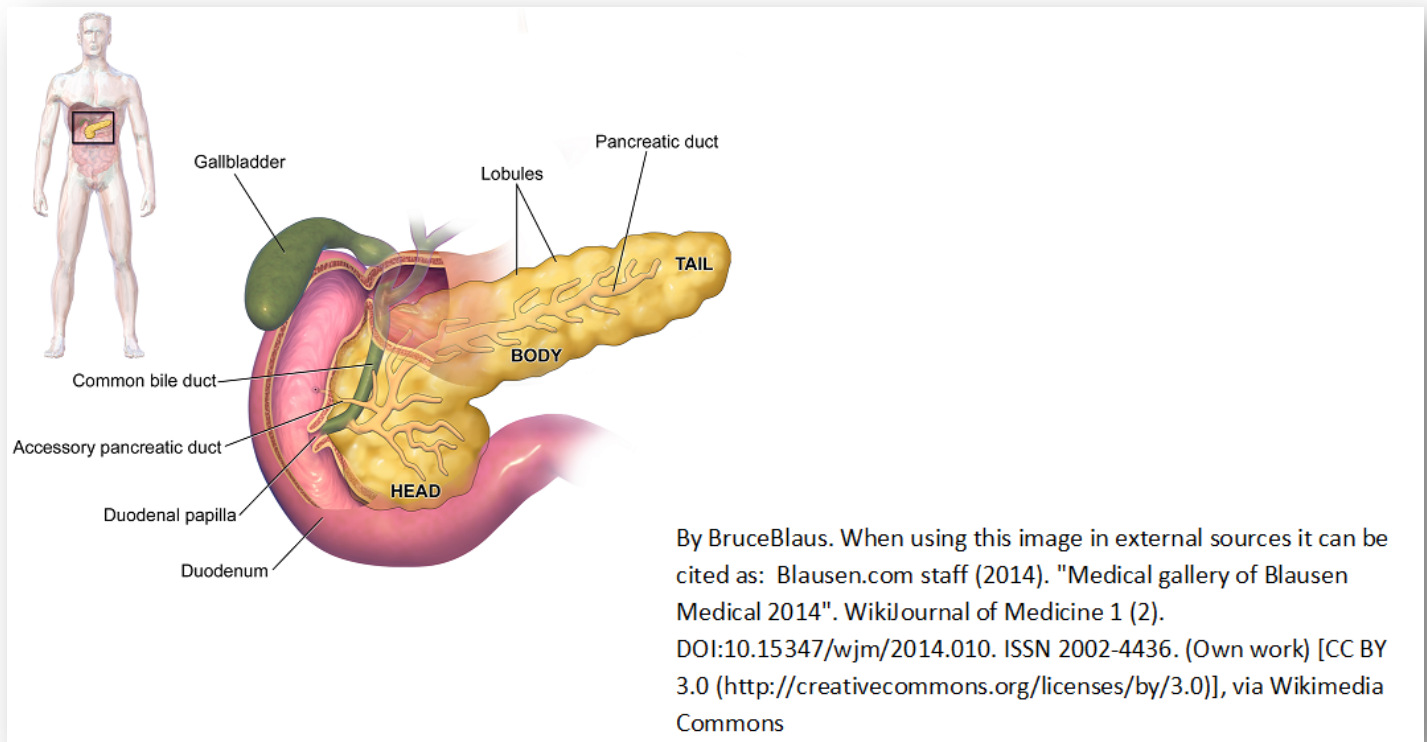
The bottom line: we see an increase in blood calcium. In children with a Vitamin D deficiency, not enough calcium or phosphorus are absorbed, thus bone development is retarded, hence the pathology known as Rickets result.

In hypoparathyroidism, calcium concentrations are low... tetany can result. We see sporadic contractions of skeletal muscles and generalized convulsions.

Chapter 25- The Endocrine System

In hyperparathyroidism, blood calcium concentration is high, and can cause damage to organs such as the kidney and even arteries.

Pancreas



This gland is both endocrine (no ducts) and exocrine (has ducts, secretes enzymes)

Alpha cells (20%): secrete glucagon which causes glycogen breakdown, hence blood sugar rises

Beta Cells (70%): secrete insulin which lowers blood sugar, as well as enhancing the synthesis of fats and proteins, and transport of amino acids.

Insulin and glucagon control blood glucose; their combined activity controls the concentration needed for homeostasis (steady state or equilibrium state in which the internal environment remains relatively constant).

★ Glucose is stored as glycogen

Somatostatin (under 10%): made by delta (D) cells, involved with inhibiting the secretion of insulin and glucagon. This is actually classified as an “inhibitory” hormone. These somatostatin cells are also found in the stomach as well as the small intestine!!

Alpha, Beta, Delta cells compromise the main endocrine portion of the pancreas. They take the form of many small clusters, and are called Islets of Langerhan’s or just islets!

Chapter 25- The Endocrine System

Overall... these hormone producing cells make up 2% of the mass of the pancreas! Other duties of this organ will be making digestive enzymes (proteases, amylases, and lipases), in addition to bicarbonate ion, HCO_3^- , secretion.

In **diabetes mellitus**, we note an insulin deficiency or a decrease response to insulin in the tissues. Glucose, instead of going into cells, is excreted. You are essentially peeing out your fuel source! Thus, if sugar (glucose) is found in the urine, diabetes could be the pathology.

In Type I diabetes:

Autoimmune disorder

Beta cell destruction... white blood cells mistake them for foreign invaders

Treatment consists of insulin

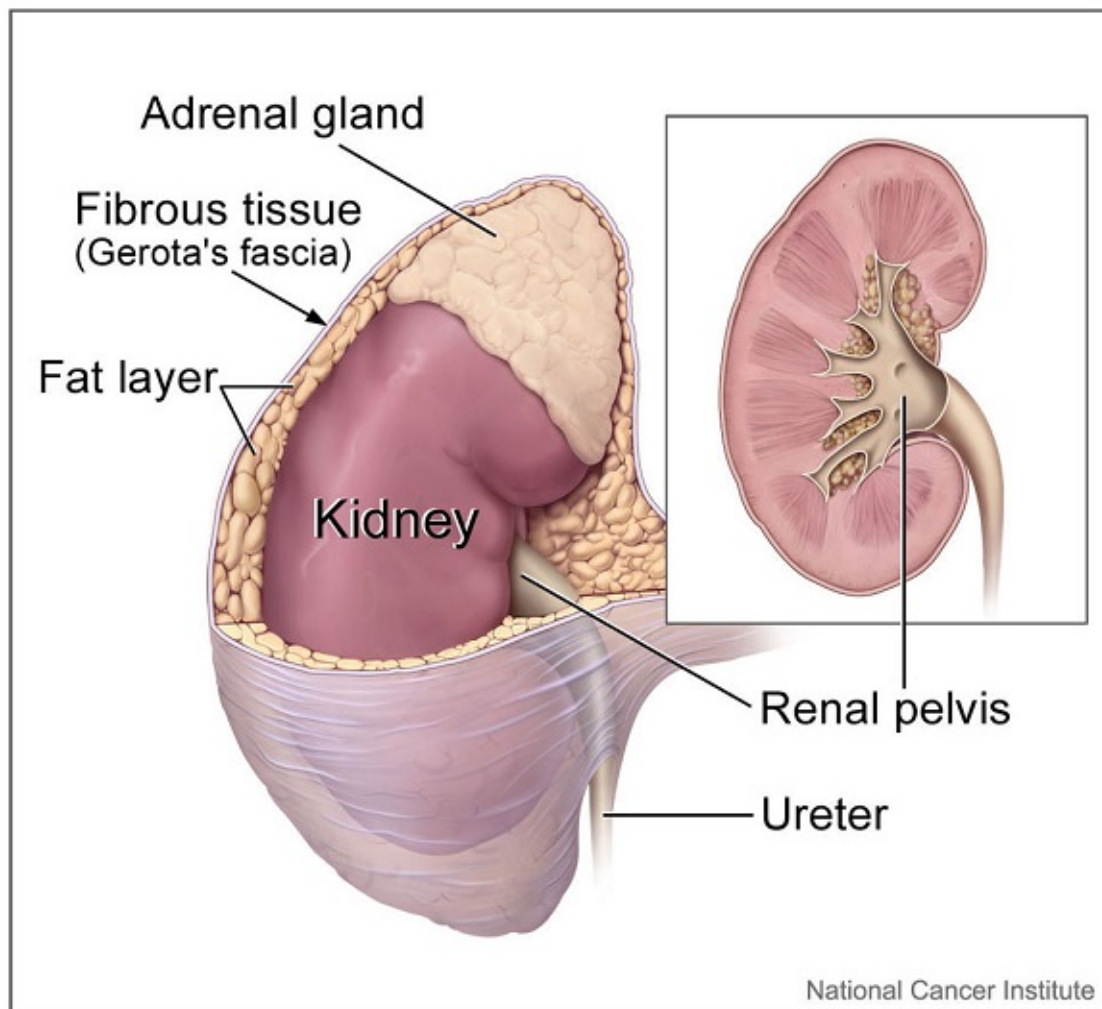
In Type II diabetes:

Insulin levels are close to normal, but the target cells fail to respond normally to insulin, thus glucose uptake is compromised

Obesity, age, lack of exercise are all contributing factors... top 10 leading cause of death in USA... exact cause is not known.

Chapter 25- The Endocrine System

Adrenal Glands



By Alan Hoofring (Illustrator) [Public domain or Public domain], via Wikimedia Commons

These glands sit atop of your kidneys

Outer portion = adrenal cortex

Central portion = adrenal medulla

Like the pituitary gland, this gland also has endocrine and neuroendocrine functions.

Adrenal Medulla

The medulla cells are intimately connected with the sympathetic nervous system.

Chapter 25- The Endocrine System

The medulla makes epinephrine (80%) and norepinephrine (20%), the catecholamines.

They differ in structure by a CH₃ group (these two hormones are also known as adrenaline and noradrenaline in the older literature).

These two hormones are involved with short-term stress responses such as increased blood pressure, increased heart rate, increased glycogenolysis (glycogen breakdown), and increased metabolic rate.

Norepinephrine is continuously released into circulation at low levels, while epinephrine is released only when we are under stress. There are indeed differences between these two molecules, but we need not concern ourselves further.

Catecholamines can dilate or constrict blood vessels. **Careful now:**

- 1) Blood is increased to areas of heart, brain, and skeletal muscles (dilation)
- 2) Blood is decreased to areas such as skin, kidneys, and digestive organs (constriction)

Adrenal Cortex

Produce glucocorticoids that raise the glucose level of the blood. Glucocorticoids include cortisol (hydrocortisone) and corticosterone. Let's use cortisol as our prototype. Glucocorticoids:

- 1) Stimulate gluconeogenesis particularly in the liver. Glucose is made from amino acids and glycerol.
- 2) Fatty acid breakdown... for energy production
- 3) Cause breakdown of skeletal muscle where the amino acids are made into glucose when needed

Sometimes glucocorticoids can be used as anti-inflammatory agents to treat diseases like arthritis. They act by decreasing the body's immune cells. Cushing syndrome is caused by too much cortisol, while Addison's disease by too little cortisol.

The cortex also makes the mineralocorticoid aldosterone.

Aldosterone is made along with the lesser hormone deoxycorticosterone. **(For the DAT, just worry about aldosterone).**

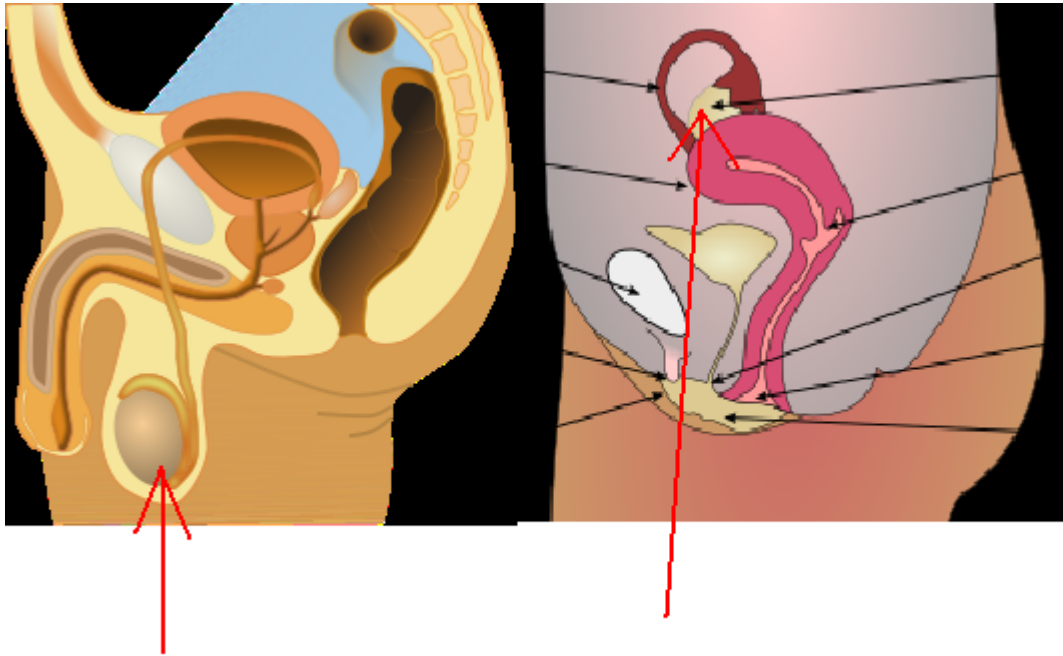
Aldosterone stimulates kidney cells to reabsorb **sodium** along with water. This increases blood volume, hence increases the blood pressure.

Aside note: 3 layers are defined to the adrenal cortex:

- a) Zona glomerulosa = mineralocorticoids
- b) Zona fasciculata = glucocorticoids
- c) Zona reticularis = androgens

Chapter 25- The Endocrine System

Gonads (testes and ovaries):



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Primary reproductive organs which make and secrete gametes (sperm and eggs) and some sex hormones.

Testes: in the male

Ovaries: in the female

The gonads make and secrete 3 types of steroid hormones:

- 1) Estrogens
- 2) Progestins
- 3) Androgens

Estrogens:

Development of female sex characteristics, growth, egg cell maturation, preparing the uterus for pregnancy and its maintenance.

A type of estrogen is called estradiol. Estradiol controls the way fat is distributed in the female. Males also have estradiol, but in much lower amounts. Estradiol is made in the male testes and adrenal glands.

Made in the ovaries- **triggers the luteal surge** to release an egg (2° oocyte) from the follicle

Progestins:

We include progesterone, here also is involved with preparing and maintaining the uterus for pregnancy. Directly effects breast development in the female, regulates mucus produced by the glands of the uterine cervix

Chapter 25- The Endocrine System

Androgens:

Include the male sex hormone testosterone. It is involved with:

Male secondary sex characteristics

Muscle building

Sperm formation

Growth and development

Hypothalamus... again!!

Besides ADH and oxytocin it makes a hormone called **GnRH... gonadotropin-releasing hormone**. This stimulates the release of FSH and LH from the anterior pituitary gland.

Thyrotropin-releasing hormone: stimulates TSH release

Growth hormone-releasing hormone: stimulates GH release

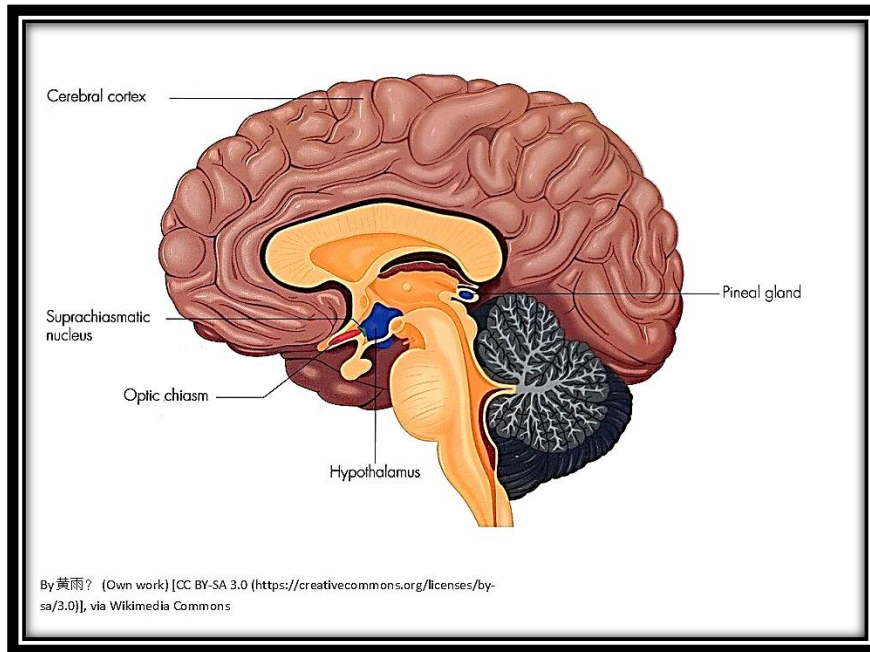
Corticotropin-releasing hormone: stimulates ACTH release

Dopamine (Prolactin-inhibiting hormone): inhibits Prolactin release

★ Dopamine is also involved with pleasurable feelings, learning, and moods!!

Chapter 25- The Endocrine System

Pineal Gland



The third eye

Located in the brain... pine cone shaped

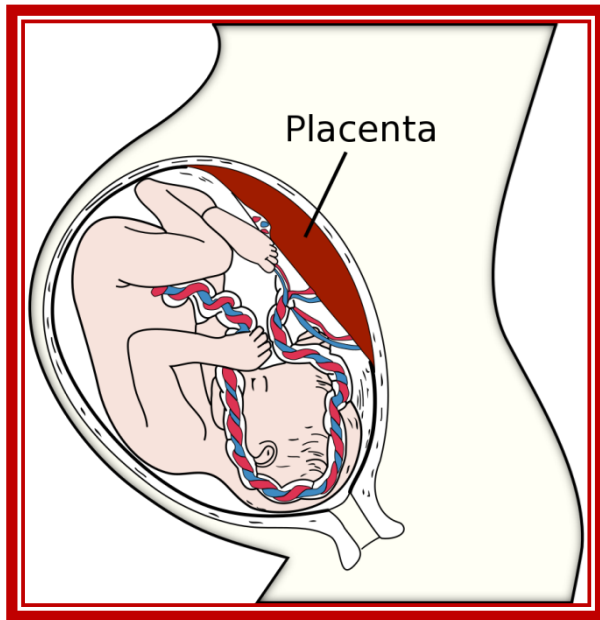
Produces melatonin... can make you sleep (pinealocytes)

Involved in biological rhythms

★ Melatonin production is stimulated in darkness and inhibited when there is light.

Chapter 25- The Endocrine System

Placenta



Organ found in pregnant female, allows for exchanges between mother and fetus without mixing their bloodstreams

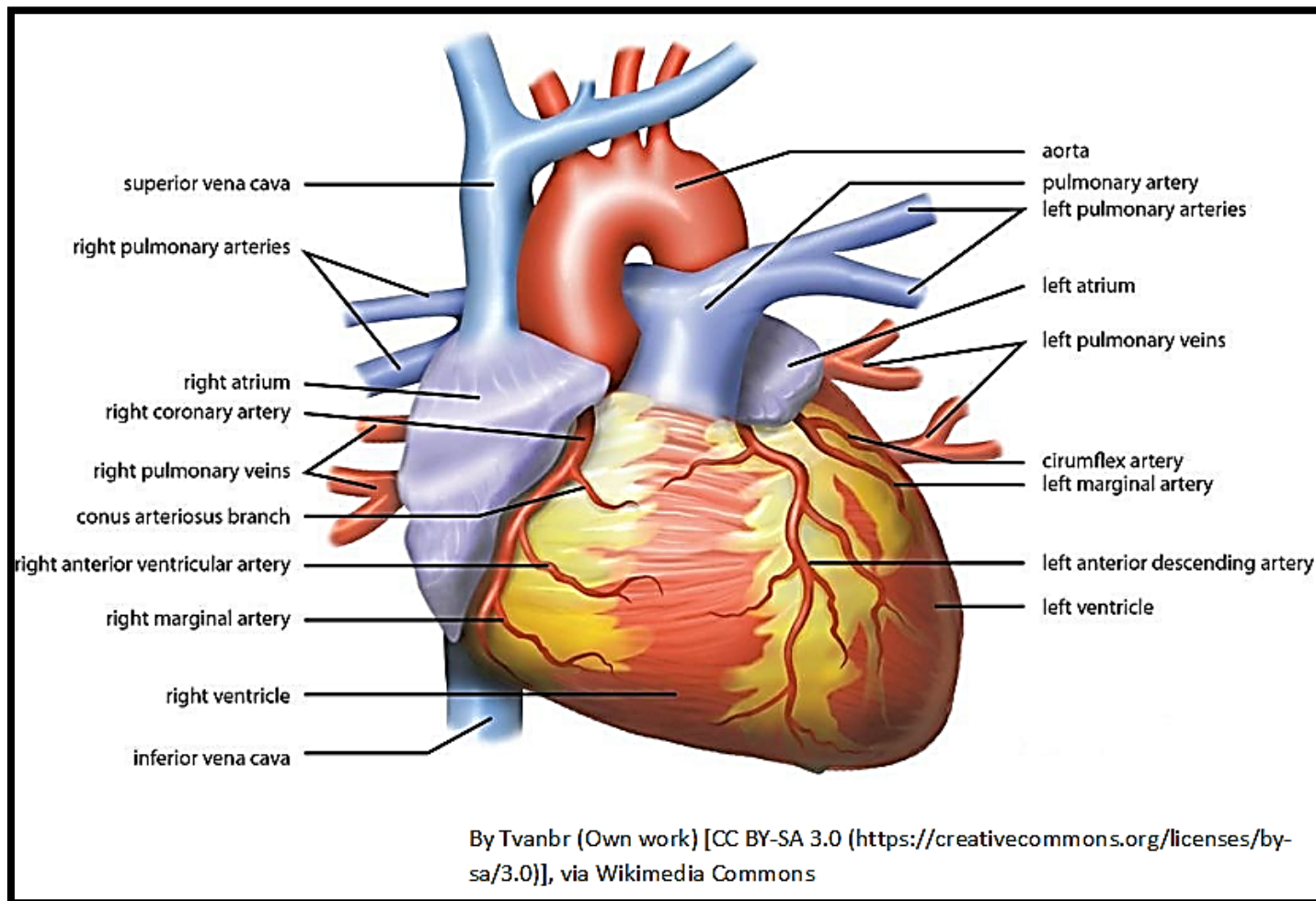
Makes **progesterone and estrogen**

Human Chorionic Gonadotropin or **hCG** (this is what a pregnancy test looks for to see if you are pregnant!!)

Relaxin: works with progesterone to help maintain pregnancy. It also helps to relax the pelvic ligaments at the end of gestation, and helps dilate and soften the cervix in preparation for birth.

Chapter 25- The Endocrine System

The Heart!!

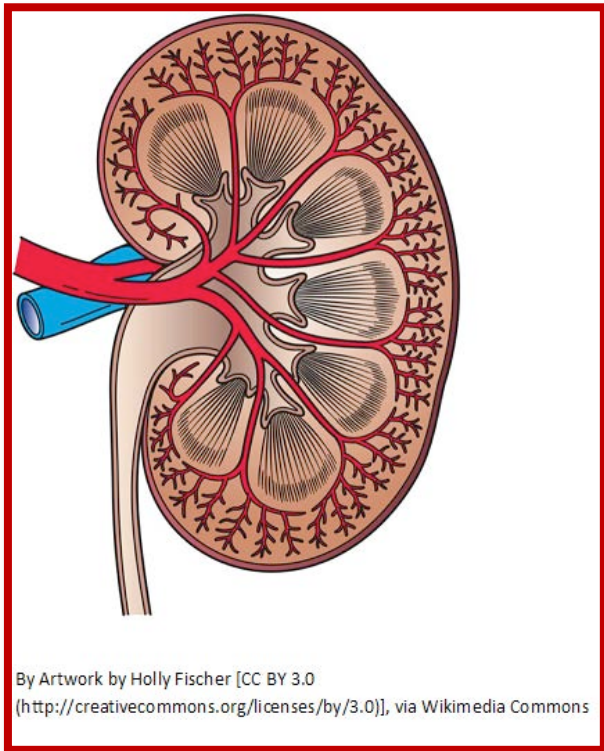


The heart as an endocrine gland? Yes, indeed!

ANP or **Atrial Natriuretic Peptide** is a cardiac hormone. This hormone is involved with lowering of the blood pressure by relaxing the arterioles, and inhibiting the reabsorption of Na^+ by the kidney.

Chapter 25- The Endocrine System

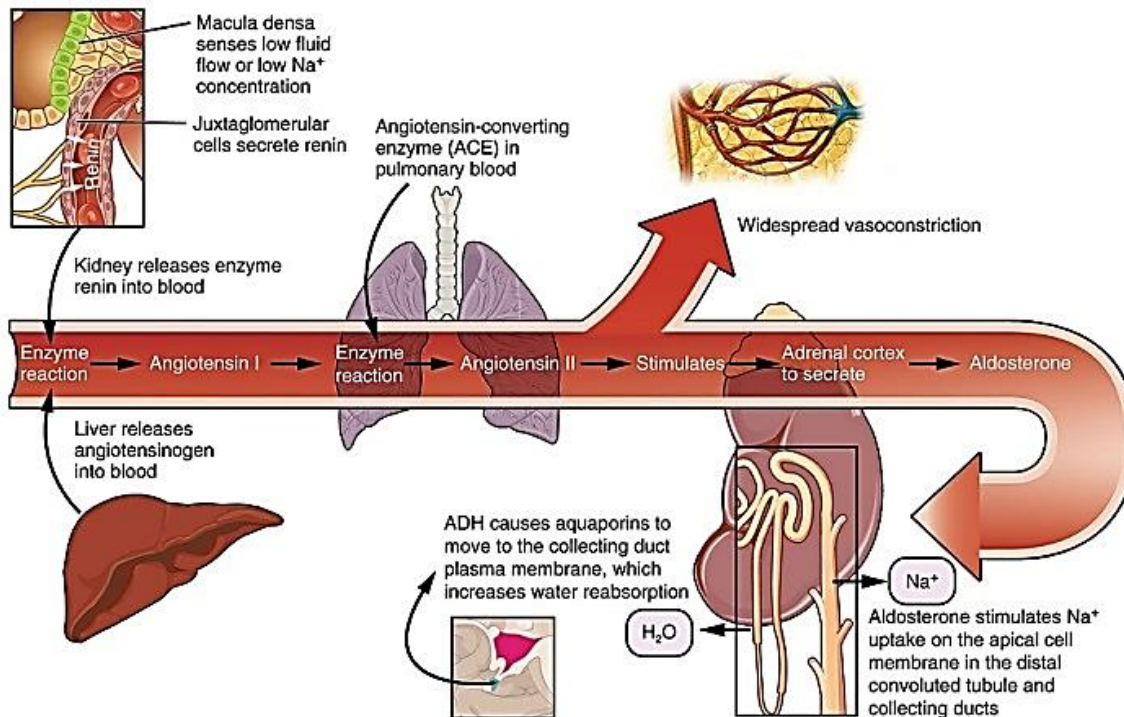
The Kidney



EPO or **erythropoietin** is made primarily in the kidneys. EPO binds with bone marrow receptors to stimulate the production of red blood cells.

Chapter 25- The Endocrine System

Renin is also made in the kidney. It is involved with blood pressure regulation. Its primary function is to cause an increase in blood pressure.



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Negative-feedback loops are an important and vital part of many hormone pathways if homeostasis is to be maintained. Think of a furnace in a building; it turns on when it gets cold, and shuts down when it gets hot. When the concentration of a hormone reaches a certain level, its concentration may drop and it becomes inhibited. If the body needs more T_4 , the hypothalamus stimulates the anterior pituitary gland to produce more TSH. The thyroid now begins to make the needed T_4 . When T_4 levels are adequate, the hypothalamus stops stimulating the anterior pituitary gland. This is a negative feedback. Calcitonin and PTH are also involved in this negative-feedback loop.

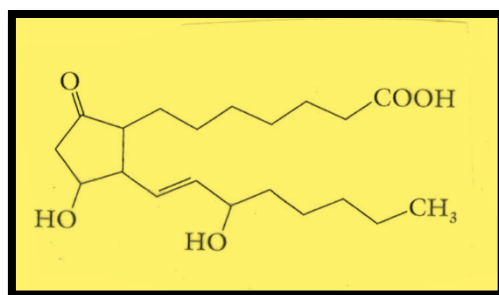
Chapter 25- The Endocrine System

What is ecdysone?

This is an insect hormone. It is involved with molting and metamorphosis in insects. It is a steroid hormone made by glands in the thorax. Juvenile Hormone, JH, is made in insect brains and is involved with larva growth.

What are Prostaglandins?

These are modified fatty acids, with hormone-like effects in animals. This prostaglandin is derived from an



acid called arachidonic acid:

Prostaglandins are made by many cells and are involved with promoting fever and inflammation. Almost all nucleated cells produce these molecules. They contribute to the **cardinal signs of inflammation**: redness, heat, swelling, and pain.

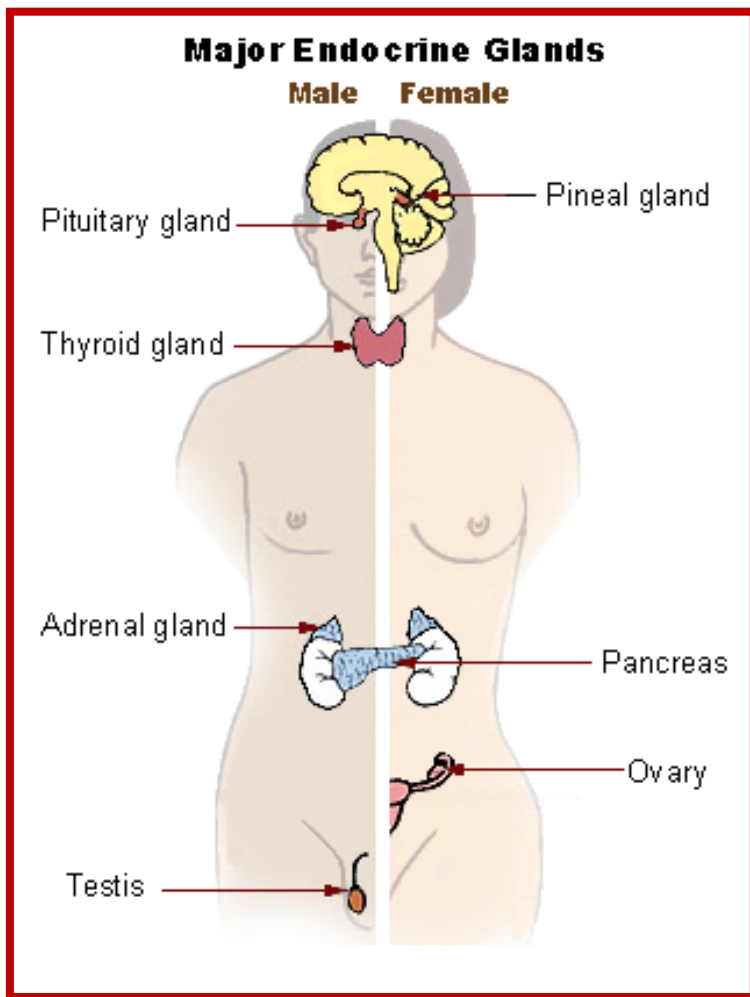
They inhibit platelet aggregation in blood... they act as vasodilators. Prostaglandins have many more effects, but this should suffice for our purposes.

Chapter 25- The Endocrine System

What is down regulation?

This is a process by which there is a decrease in cellular component. The component may be a protein or even RNA in response to a stimulus. If we see a decrease in cell receptors in response to a hormone, for example, this is down regulation. Elevated insulin in the blood is a specific example. With the high insulin, it is possible to see a reduction in receptors. This is what is seen in Type 2 diabetes.

In up regulation, we see a response that is opposite. We see an increase in cellular components like RNA or protein. For example, liver cells will increase the production of cytochrome p450 enzymes when exposed to dioxin. This will allow for the breakdown of these molecules.



Chapter 26- Sense Organs

Sense Organs

Tongue:



Complex muscular organ; largest structure in oral cavity.

Serves numerous functions including:

- a) Swallowing
- b) Perception (can detect taste, texture, pain, pressure, etc.)
- c) Speech
- d) Respiration
- e) Jaw development

Extrinsic muscles: move tongue in and out and side to side

Intrinsic muscles: alter the shape of the tongue

Receptor cells are organized into modified epithelial cells called **taste buds**. Taste buds are seen in several areas; most are associated with nipple-shaped projections called **papillae**. About 3000 taste buds are on the tongue. There are 4 primary taste sensations: sweet, sour, salty, and bitter.

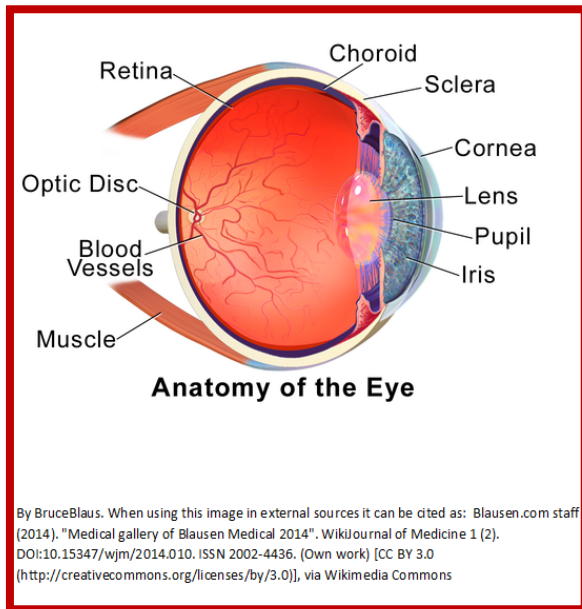
Taste perception is a tricky affair; it also involves the smell receptors. This is evidenced by the decreased taste ability of people who get colds and are congested... We can't taste very much!

Von Ebner's glands surround the papillae and secrete salivary lipase, beginning the process of lipid breakdown (hydrolysis) in the mouth.

In dental school, you will learn that different types of papillae exist, but for our purposes, this will suffice.

Chapter 26- Sense Organs

Eye



Highly developed photosensitive organ that analyzes form, light intensity, and color.

Sclera: white area of the eye... tough connective tissue made up of collagen bundles, it is avascular, but has sensory receptors for pain.

Cornea: allows light into the eye; avascular when light strikes the cornea, it bends (refracts) the incoming light onto the lens of the eye.

Choroid: highly vascular thin layer that lines most of the internal sclera surface. Melanocytes containing pigments are here which can absorb the light that photoreceptors have not and prevents light scattering within the eye.

Iris: colored portion of the eye and is continuous with the choroid

Pupil: opening in the iris center that controls the amount of light that enters. The size of the pupil determines how much light enters the eye. Sympathetic stimulation: dilates pupil, Parasympathetic stimulation: constricts pupil

Lens: located behind the pupil, it will focus light onto the retina, the ciliary muscle will change the shape of the lens

Retina: the posterior portion of the eye that contains the photoreceptors:

Rods: for dim light and black- and- white vision

Cones: provide color vision, respond well to daylight color and responsible for visual acuity

Rods and cones found in the retina vary from animal to animal. Amphibians, fish, reptiles and even birds see color. Night animals have a high proportion of rods in their retina. This clearly is a favorable adaptation.

Chapter 26- Sense Organs

Cones are concentrated in a depression near the center of the retina called the fovea centralis... this is the area of “Keenest Vision” **and a common exam question!!** The Fovea has no rods.

The Optic Nerve leaves the eyeball at an area called the **optic disc** or “physiologic blind spot”. At the optic disc... there are no photoreceptors and it is insensitive to light, hence the name blind spot.

Note: Recall, that the lens of the eye changes shape. Lens becomes flattened for distant vision, ciliary muscle relaxes. In **close up vision**, lens becomes more **spherical**, ciliary muscle contracts.

Eyeball shape is maintained by the jellylike vitreous humor. Makes up 80% of the eyeball. Very few cells are found here, but phagocytes are found to aid in cleaning up cellular debris.

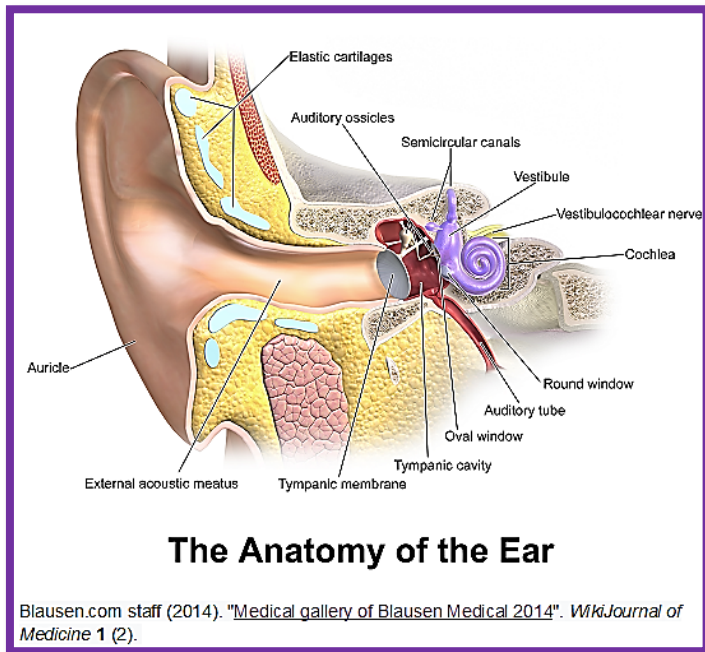
Aqueous humor: clear, slightly alkaline fluid found in anterior and posterior eye chambers. It resembles blood plasma, but has less protein and glucose. It is involved with water removal, and it brings O₂, and nutrients to the eye.

What is rhodopsin?

This is also called “visual purple”, and is a pigment-containing sensory protein that converts light into an electrical signal. This pigment is found in rods. Rhodopsin is very sensitive to light, and allow us to see in dim light. When rhodopsin absorbs light, it isomerizes from its cis-conformation to the trans-conformation. This molecular geometric change causes an electrical signal to be sent to the brain, and a visual image is seen. Much is still not understood on this mechanism, so relax if it seems a bit bizarre!

Chapter 26- Sense Organs

Ear



Many arthropods and most vertebrates are able to hear or perceive sound. A sound is a wave of compressed air. The ear has an external, middle, and inner part.

External Ear:

Pinna: your outer ear you touch

Auditory canal... collects the sound waves that enter the ear. These waves are channeled to the cone-shaped eardrum (tympanic membrane). The tympanic membrane vibrates in response to the sound wave.

Middle Ear:

Vibrations are transmitted to the three bones: incus, malleus, and stapes.

These bones actually form a “bridge” connecting the tympanic membrane to the inner ear. Vibrations move to the oval window before moving to the inner ear. The oval window is a membrane that causes vibrations to move to the inner ear.

The **eustachian tube** connects the middle ear to the nasopharynx and ensures that air pressure is equalized on either side of the eardrum.

Did your ears ever “pop” when changing altitude in a plane? The eustachian tube is what enables you to equalize the pressure difference and restore your hearing to normal!!

Chapter 26- Sense Organs

The Inner Ear:

Consists of fluid-filled channels in the bones of the skull. One of those channels is called the **cochlea**. This is a snail-like structure which contains a sensory receptor called the **organ of Corti**. This organ of Corti holds the hair cells, the nerve receptors for hearing... the mechanoreceptors of the ear!!

The movement of middle ear bones exerts pressure on the cochlea. The fluid in the cochlea stimulate tiny hair cells. The signals from these hair cells are changed into nerve impulses... Impulses are carried to the brain by the auditory nerve. Also in the inner ear are the semicircular canals, the utricle, and saccule. These structures are involved with balance. **A common exam question!!**

In deafness, several factors can be involved:

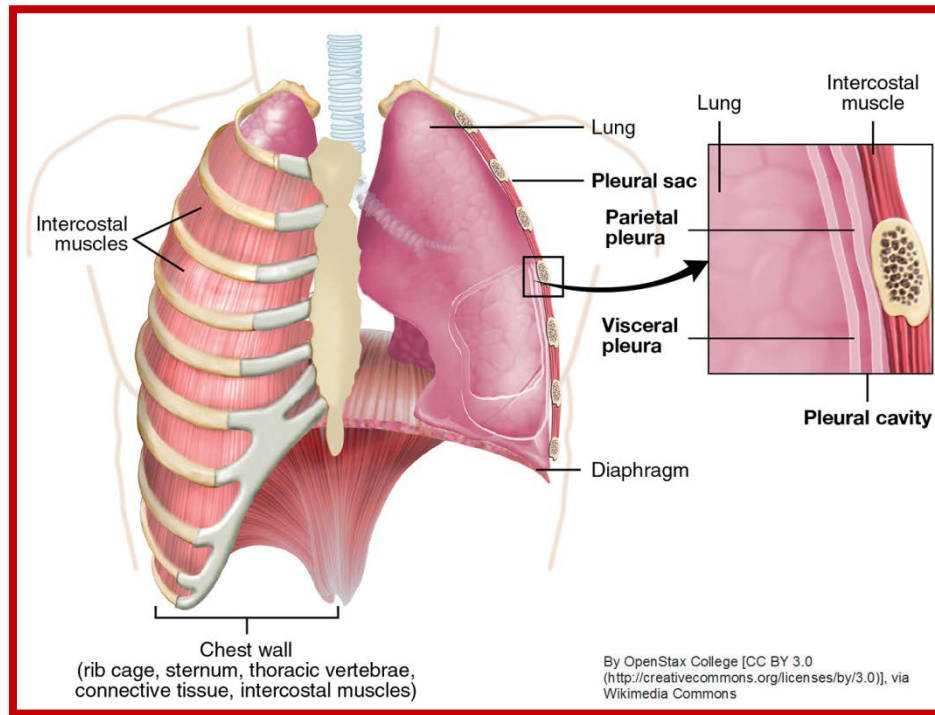
- a) Cochlea damage
- b) Auditory nerve damage
- c) Vibration transmittance to inner ear is hindered
- d) Loud sounds

Insects also detect sound waves. They use a tympanic membrane which allows sound waves to vibrate and receptor cells convert the sound waves into nerve impulses.

Fish lack a tympanic membrane and a cochlea. Many fish conduct sound waves through a series of bones. Mechanoreceptors are able to detect sound waves which are converted into neuronal signals.

Chapter 27- Respiratory System

Respiratory System



This system filters the incoming air, transports it to the lungs for gas exchange.

Organs of this system include:

Nose, nasal cavity, sinuses, pharynx, larynx (voice box), trachea, bronchiole tree, and lungs.

Amphibian lungs, when present, are small and are not a very effective gas exchange mechanism. Amphibians rely heavily on gas diffusion across body surfaces such as skin to carry out gas exchange. This is a **favorite DAT type question**.

Most reptiles, birds, and all mammals depend on lungs for gas exchange. Birds, reptiles, and mammals use a **negative pressure system** that allows air in by **inspiration**.

If you stop breathing, even for five minutes, the normal brain function is likely to be gone forever.

Air enters the nasal cavity which contains ciliated epithelial cells and hair that will filter dust and particles from the air, as well as olfactory receptors that detect smell.

The nasal cavity is divided medially into a left and right portion by the **nasal septum**. If it bends toward one side due to injury or old age, we call it a **deviated septum**. A deviated septum can make breathing difficult.

The mucous membrane that lines the nasal cavity is rich in blood vessels, thus air that passes over is quickly warmed. The sticky mucous also aids in entrapping dust and small particulates of matter from the air. As the cilia moves, the mucous-entrapped particles are pushed toward the pharynx... which is the back of the throat. When this occurs, the mucus is swallowed. Gastric juice usually destroys the microorganisms in the mucus... this helps to prevent respiratory infections.

Chapter 27- Respiratory System

Air-filled spaces located within the facial bones are called **sinuses**. Lined by mucous membranes, they drain into the nasal cavity. If the sinuses are blocked due to an infection, pressure due to accumulating fluid occurs, and a headache can occur.

The pharynx = intersection of food and air (the first portion is called the nasopharynx)

From the pharynx, air passes through an opening called the **glottis** to the **larynx** or “voice box”, which sits at the top of the trachea.

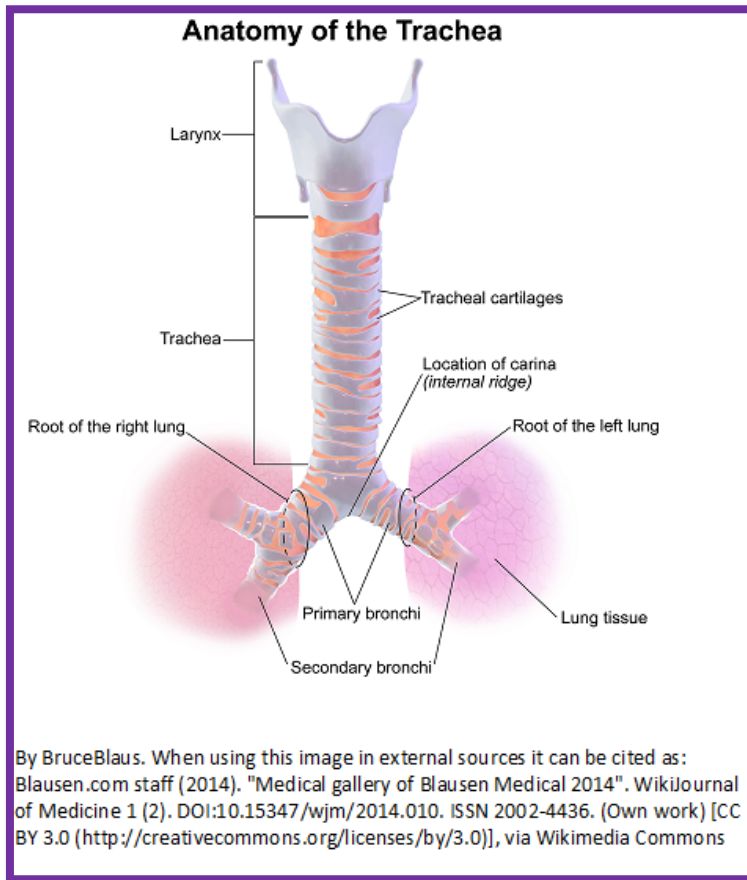
During swallowing, a flap of tissue called the **epiglottis** covers the glottis, and closes it off temporarily. Thus, the epiglottis prevents food from entering the trachea.

The larynx is composed of cartilage and muscles bound together by elastic tissue.

Inside the larynx, we find the **vocal cords**. The contracting or relaxing of these cords will determine the vocal sounds. If the mucous membrane of your larynx gets inflamed from infection or overuse, the vocal cords cannot vibrate as freely, hence you sound hoarse and have **laryngitis**.

Chapter 27- Respiratory System

The Trachea



Made of cartilage to prevent collapse

Contains cilia-bearing cells and many **goblet cells** that make mucus.

★ **Hyaline cartilage** reinforces tracheal wall.

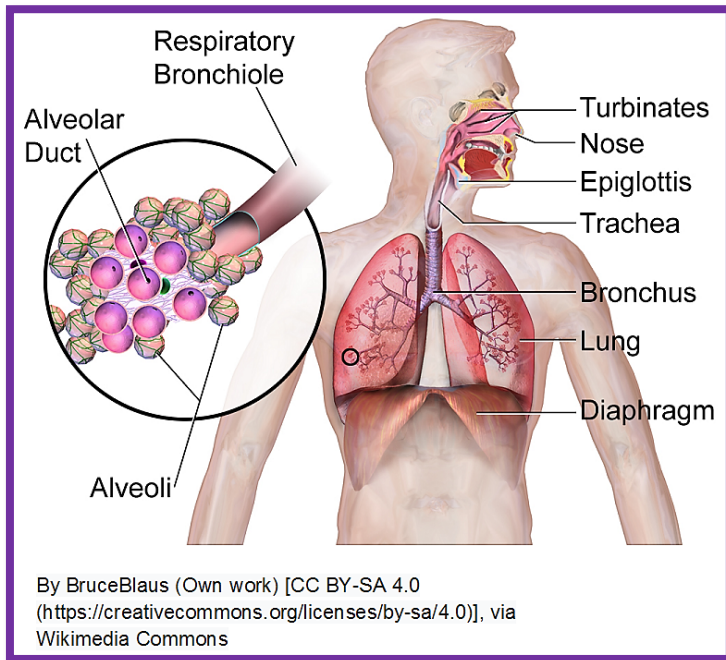
Hyaline cartilage is the most abundant cartilage. It is found at the ends of long bones, larynx, trachea, bronchi, and in ventral ends of ribs.

The trachea divides into two **bronchi** that carry air to the left and right lungs. The bronchi branch into small passages called **bronchioles**. The bronchi and larger bronchioles have cartilage rings like the trachea, as well as ciliated linings. Small bronchioles less than 5 mm have neither glands nor cartilage, but do have a few goblet cells. Dome-shaped cells called **Clara cells** containing short microvilli are noted in the small bronchioles. Some scientists call these cells club cells. Basically, they help detoxify the lung from harmful substances. Toxins are degraded via P-450 enzymes. Studies also suggest Clara cells produce a surfactant-like material which aids in reducing the surface tension in the bronchioles. In **asthma** bronchioles constrict, reducing the diameter of the air passages. A person has a difficult time in breathing and produces a wheezing

Chapter 27- Respiratory System

sound as air is passed through the constricted passages. Drugs such as epinephrine cause the smooth muscles to relax and breathing is improved.

The smallest bronchioles terminate in the **alveolar sacs** which have “bulges” called **alveoli**. Hundreds of millions of alveoli represent the chambers in which gas exchange occurs. Alveoli are highly vascular and very thin-walled.



Alveoli are responsible for the spongy structure of the lungs. Alveolar macrophages known as dust cells, are found on the alveolus surface, among other places. Dust cells phagocytose bacteria and dust and allow for a sterile lung environment.

★ The first breath of a newborn, stimulated by CO₂ must be forceful because the lungs are collapsed. Surface tension holds the moist membranes together (think hydrogen bonding) ... a chemical called surfactant reduces the surface tension, and after the first powerful breath, the lungs stay expanded. Surfactants are present in the alveoli.

Surfactants contain a mixture of proteins and phospholipids.

Premature babies suffer from a lack of surfactant, but artificial surfactant is available.

During inhalation in mammals, the **thoracic cavity is expanded**, and the **diaphragm contracts** and therefore **moves down**. This is negative pressure breathing.

The **phrenic nerve** carries impulses to the diaphragm (classified as skeletal muscle), which causes it to contract and move downward. The thoracic cavity is now increased. The external muscles called **intercostal muscles** contract too, raising the ribs and causing the thoracic cavity to increase some more. As the increase in size of the thoracic cavity occurs, the internal pressure is now decreased. The higher atmospheric pressure forces air into the respiratory tract and the air passages and the lungs inflate.

Chapter 27- Respiratory System

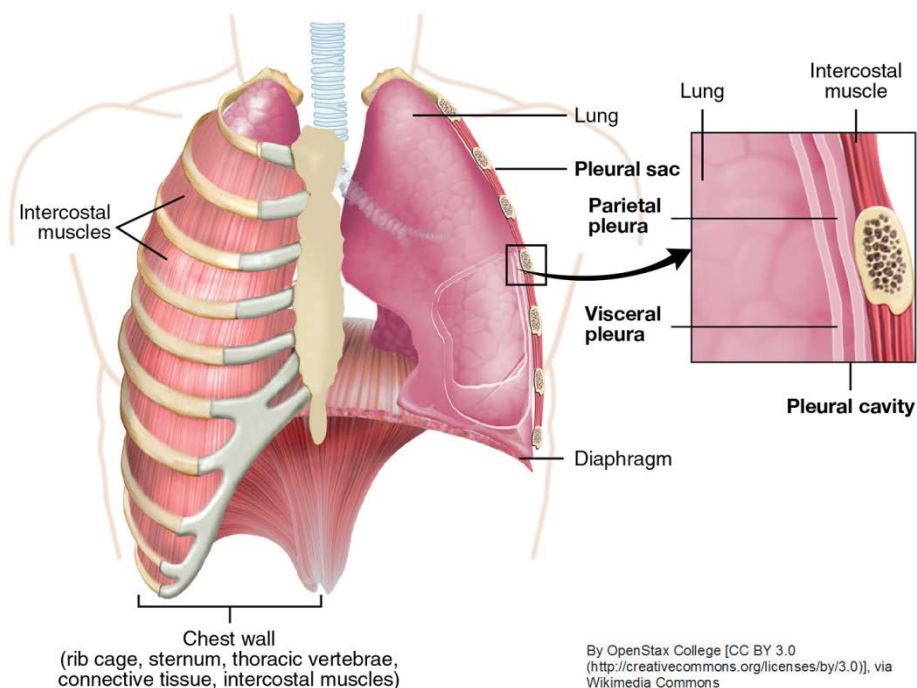
During expiration, the diaphragm and external respiratory muscles relax, and a “recoil” occurs. The elastic tissue of lungs, abdominal organs, etc. suddenly spring back; this causes air pressure within the lungs to increase. Air will then be squeezed out of the lungs into the air passages.

Tidal volume = the volume of air that flows into or out of the lungs with each breath.

The tidal volume during maximum inhalation and exhalation is called the **vital capacity**.

After you exhale, some air still remains in the lungs, this is called the **residual volume**.

Lungs



We have two lungs, covered by a serous membrane called the **pleura**. The lungs are cone-shaped organs that occupy a large percentage of the thoracic cavity.

Right lung: larger than the left lung and has three lobes (superior, middle, inferior)

Left lung: smaller... why? To make room for the heart and its vasculature. Has two lobes (superior and inferior)

Non-respiratory air movements include:

Laughing

Crying

Yawning: thought to aid respiration; allows more O₂ to the blood

Sneezing: clears upper respiratory passages

Hiccup: spasmodic contraction of the diaphragm

Chapter 27- Respiratory System

Breathing is under the control of two main areas of the brain: **Medulla Oblongata**, and **Pons**

The pH of the surrounding tissue gives important information regarding CO₂ levels.

As metabolic activity goes up (you are working out), the CO₂ in the blood increases as lactic acid is produced, hence the pH is lowered. The Medulla will respond by increasing the breathing rate.

Very important DAT concept here, peeps!

If you notice, it is the CO₂ that has the effect on breathing control centers, not the O₂ concentration in the blood.

If, however O₂ levels did drop low... in times of hypoxia or if you decided to climb Mt. Everest, O₂ “sensors” located in the aorta and carotid arteries can signal the brain to increase the breathing rate. These “sensors” are chemoreceptors. (The carotid body can detect changes in blood gas composition. This small cluster of chemoreceptors is very sensitive to pH and even temperature changes).

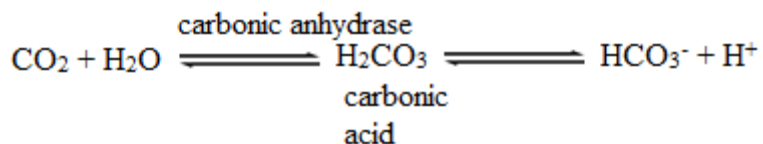
CO₂ Transport

Most CO₂ is carried in the blood as HCO₃⁻ or bicarbonate ion 70%

20% is transported by hemoglobin (carbamino hemoglobin)

10% is in blood plasma

In red blood cells, we see the following reaction occur:



The HCO₃⁻ goes into plasma, H⁺ is captured by hemoglobin. Hemoglobin acts as a ?.

I hope you said buffer!! Clearly you see, that hemoglobin prevents the blood from getting too acidic!!

The HCO₃⁻ diffuses into the plasma, and is carried to the lungs. In the lungs, we reform H₂CO₃ (combining the HCO₃⁻ with H⁺ from the hemoglobin).



This H₂CO₃ then becomes CO₂ and H₂O. Some CO₂ is also unloaded from hemoglobin.

Now, the CO₂ goes into the plasma and interstitial fluid and is exhaled.

O₂ Transport

Almost all O₂ carried in the blood is done by hemoglobin, occurring in red blood cells (erythrocytes).

Chapter 27- Respiratory System

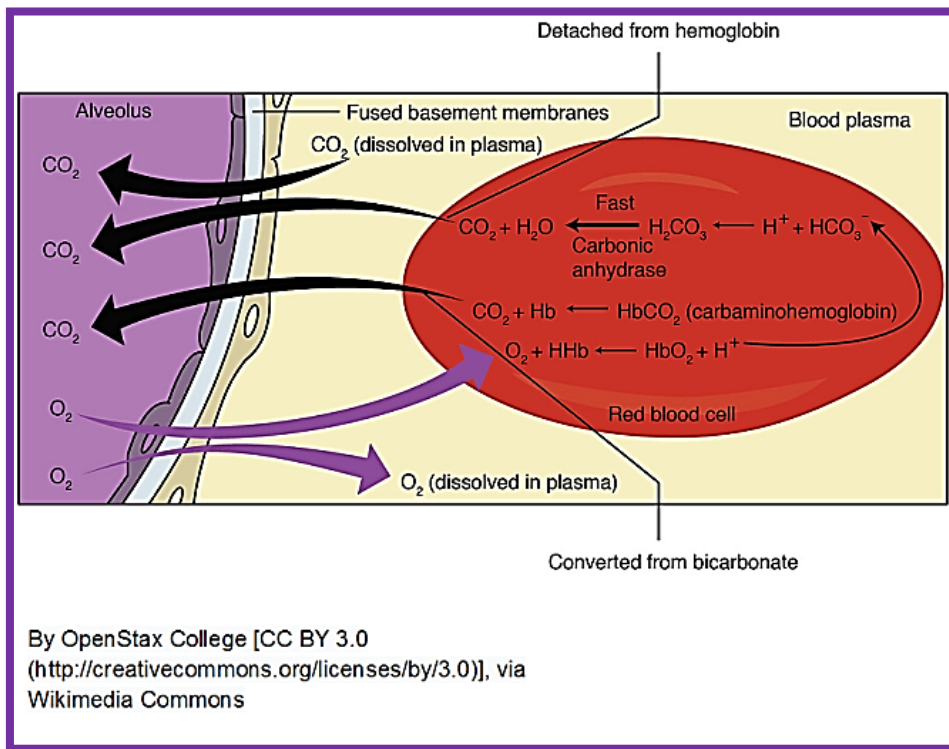
The greater the pressure of oxygen, P_{O_2} , the more oxygen can combine. $Hb-O_2$ is now called **oxyhemoglobin**. Several factors determine how much O_2 is released. Factors include: temperature, pH, CO_2 levels. As CO_2 levels rise, O_2 is released. As the blood pH decreases (i.e. gets more acidic) or as the temperature rises, more O_2 is released.

CO can also combine with Hb to form $Hb-CO$ or **carboxyhemoglobin**. It actually can form a “very tight” association with Hb. Thus, when a person breathes in CO, less H is available for O_2 transport, and cells begin to suffer.

Chapter 27- Respiratory System

Once O_2 is available to body tissues we are able to run cycles such as the citric acid cycle, electron transfer system, etc.

In insects, we have **tracheal systems** which are air tubes that branch throughout the insect. Gas exchange occurs by diffusion.



How do fish breath?

H_2O is taken into the mouth and is forced through special organs called “gills”. As H_2O passes over the thin-walled gills, dissolved O_2 moves into the blood and travels to the fish’s cells to allow cellular respiration to occur.

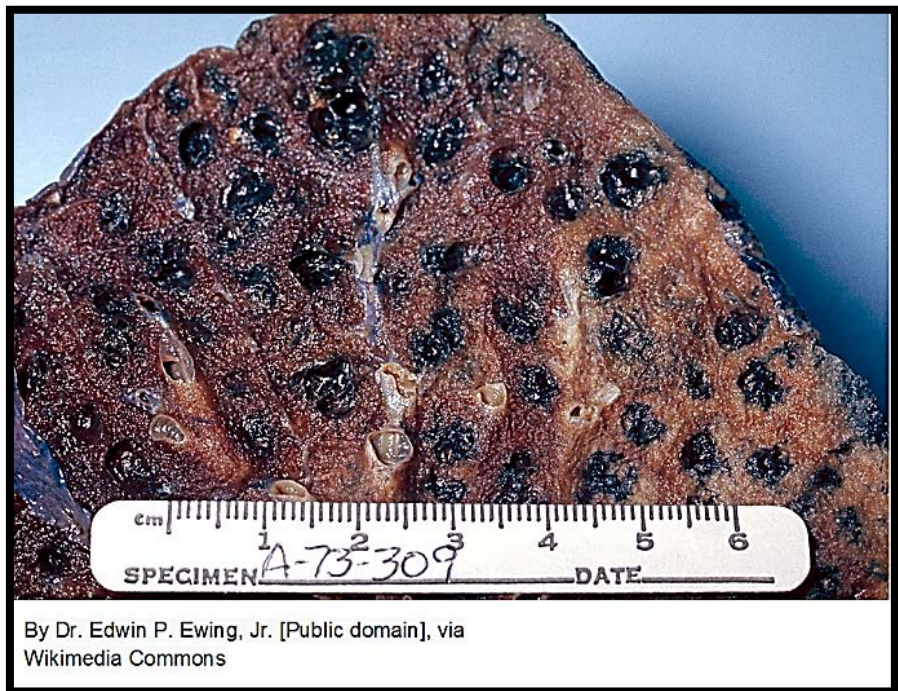
(Dolphins and whales are mammals and have lungs, thus needs to come to the surface for O_2 !!)

Believe it or not, birds have a more complicated respiratory system than mammals. Theories are still in the dozens about exactly how a bird utilizes O_2 . Constant airflow supplies birds with more O_2 than mammals... this comes in handy for flying at high altitudes. Air flow in birds is unidirectional through chambers and tubes. We need not concern ourselves any further, but much information is available to you on the internet if you would like more details.

A few lung pathologies:

Chapter 27- Respiratory System

Emphysema: alveoli are damaged and lose their elasticity and their walls break down and the sacs become larger.



Pneumonia:

Can be viral or bacterial, or even fungal

Alveoli fill with fluid or pus causing difficulty in breathing, fever, chills, etc.

Fluid accumulation around the lungs is called a **pleural effusion**. Many things can cause a pleural effusion from pneumonia to cancer. **I posted a wonderful pleural effusion slide in our DAT Destroyer study group.**

Chapter 28- Muscle

Muscle

Muscle cells are specialized for contraction and will allow the animal to move.

Muscle is one of the 4 major tissue types we have:

- 1) Muscle
- 2) Nervous
- 3) Connective
- 4) Epithelial

★ Tendons attach muscle to bone

★ Ligaments attach bone to bone

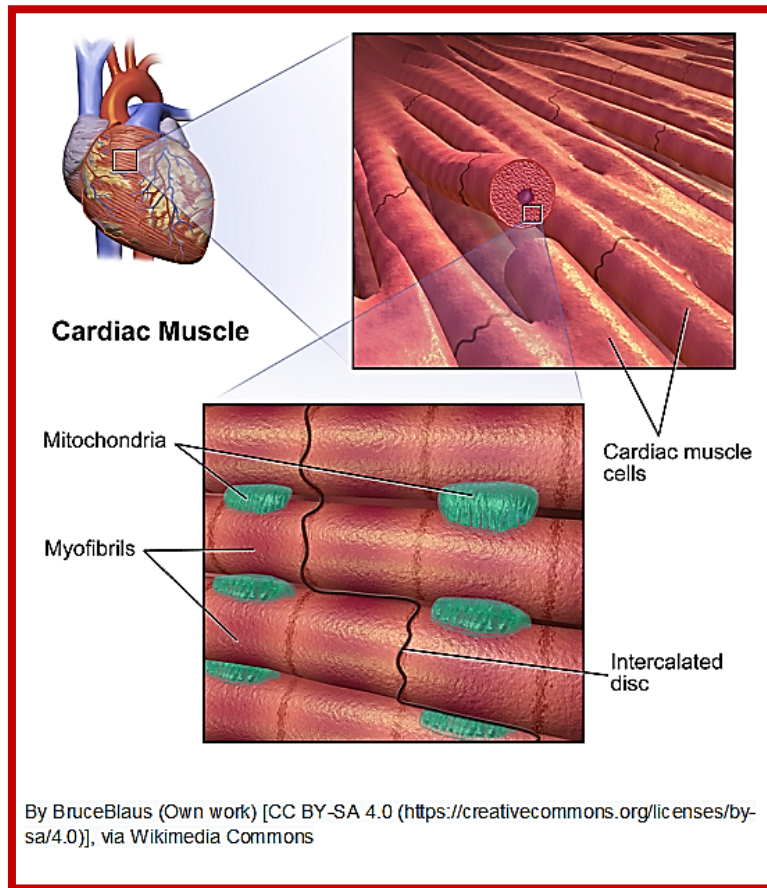
Three types of muscle tissue can be distinguished:

- a) Cardiac
- b) Smooth
- c) Skeletal

All three are derived from the mesoderm!

Chapter 28- Muscle

Cardiac Muscle



Between cells there are intercalated disks which is unique to cardiac muscle. This is a membranous boundary between adjacent cells. **Usually has a single nucleus and is striated, and is an involuntary muscle.**

This tissue makes up the bulk of the heart and is responsible for pumping the blood into chambers as well as into blood vessels.

Gap Junctions are also present which allow direct transmission of the depolarizing current to go from cell to cell. We say the gap junctions are “electrically coupled”.

Remember for the DAT: gap junctions connect the cytoplasm from one cell to another. I have a nice problem in the DAT Destroyer to show you.

40% of the cytoplasmic volume contains mitochondria, only 2% is in skeletal muscle. As you can see, heart muscle has a huge amount of mitochondria!

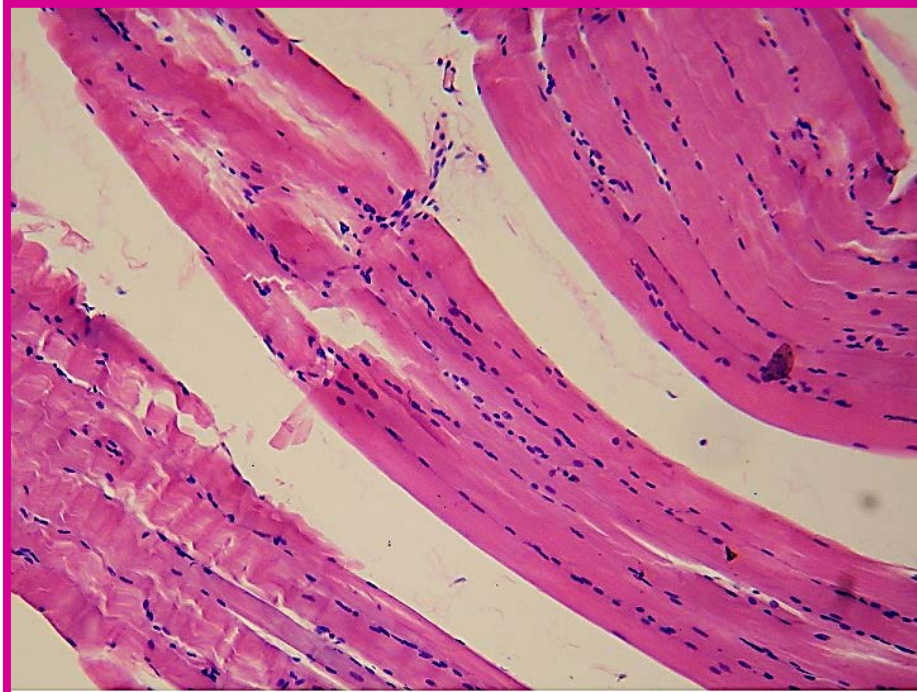
Cardiac muscle cells contain granules that contain atrial natriuretic factor, a hormone that acts on the kidneys to help lower blood pressure by allowing sodium and water loss.

Chapter 28- Muscle

In athletes or even in some pathologies, we see the cardiac cells increase in size... we call this a cardiac hypertrophy.

Damage to the heart does not result in cell regeneration, unfortunately; instead, the dead muscle cells are replaced by fibrous connective tissue.

Smooth Muscle



By Juan Carlos Fonseca Mata (Own work) [CC BY-SA 4.0
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No striations, involuntary, and has a single nucleus.

Found in walls of blood vessels, GI tract, urinary tract, reproductive tract, urinary bladder, and internal organs such as stomach and intestines.

Regulated by:

- a) Hormones
- b) Autonomic nervous system
- c) Local physiological conditions

Unlike cardiac muscle, regeneration is possible... thus can do mitosis.

Actin and myosin are not regularly arranged along the cell length, the myosin is scattered in the cytosol, and the actin is attached to structures called dense bodies... thus no striations are noted.

Chapter 28- Muscle

Ca^{++} complex with a calcium-binding protein called **calmodulin** which is involved in the contraction of the muscle. The details of smooth muscle contraction is involved and will not be needed for the DAT, thus we need not go any deeper. However, I will go into more details regarding the contraction of skeletal muscle, which is a favorite DAT topic.

Skeletal Muscle



Striated, voluntary, and multinucleated

Like cardiac muscle, the nuclei do not do mitosis. However, limited regeneration can occur. Muscle building “satellite cells” might be able to fuse with cells pre-existing to increase the muscle mass. Satellite cells reside on the external surface of muscle cells, cardiac muscle lacks these cells.

Skeletal muscle is what is responsible for moving the head, trunk, and limbs. Facial expressions, walking, talking, etc., all involve these muscles.

When stimulated by a nerve impulse, contraction occurs.

The entire muscle is surrounded by a dense connective tissue called an epimysium.

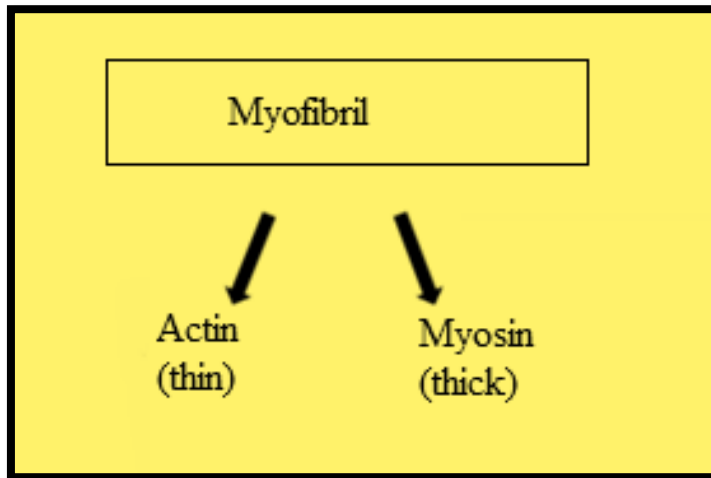
Muscle fibers can be:

- a) Red: many mitochondria, rich in myoglobin, rich in oxidative enzymes, and blood supply
- b) White: few mitochondria, poor in oxidative enzymes, poor in myoglobin, poor in blood supply
- c) Intermediate

Most muscles have all three, but the percentage will vary. For example, in chicken, the thigh is mainly red fibers, the breast is white fibers.

Chapter 28- Muscle

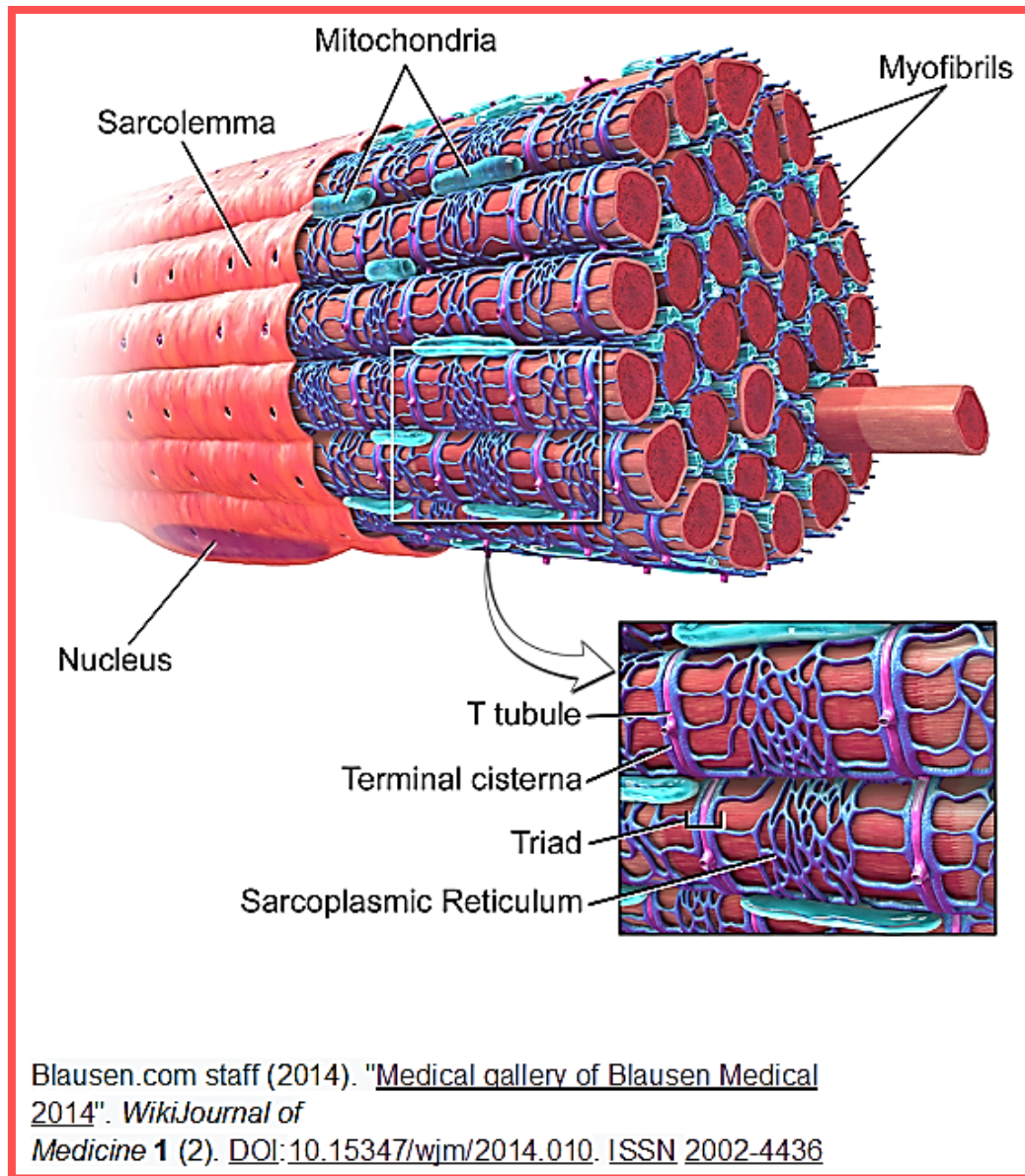
Much of the skeletal muscle consists of long longitudinal arrays of cylindrical structures called **myofibrils**.



Myofibrils are composed of thin and thick filaments.

★ Filament arrangement creates a pattern of light and dark bands (**favorite DAT question!**)

Chapter 28- Muscle



The myofibrils play a very important role in muscle contraction.

A **sarcomere** is the structural and functional unit of a myofibril.

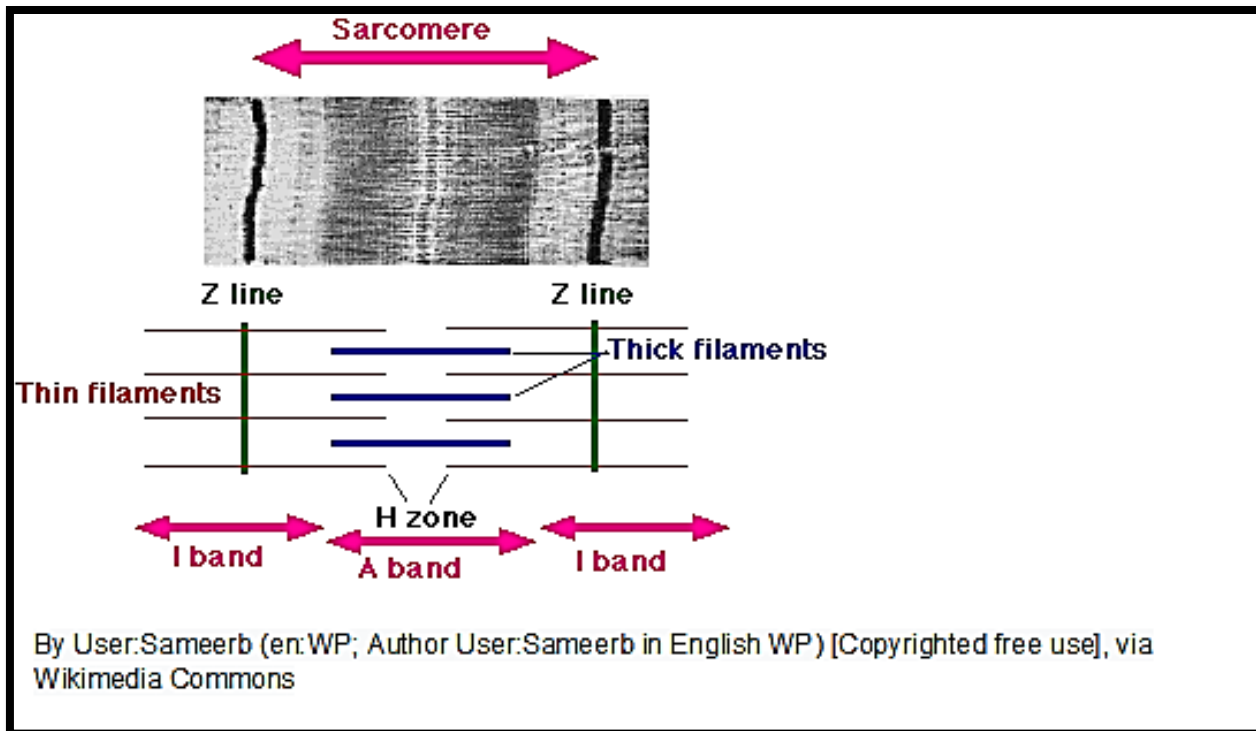
Many of my DAT classroom students seem to be very confused by this. **Make sure that you are all clear on the fact that the sarcomere is that part of the myofibril between two Z lines.**

Now... let us move in closer and examine this sarcomere:

Dark bands = A bands

Light bands = I bands

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H zone = center of A band, lighter/ pale area

Know these areas of the DAT exam!!

We need not worry about details, but titin and nebulin are two other proteins that contribute to the stability of the sarcomere.

Titin: helps position the thick filaments

Nebulin: helps stabilize the thin filaments

α – actinin is another protein also associated with stabilizing the thin filaments.

Thus... myofibril's structural organization is maintained largely by nebulin, titin, and α – actinin. **Know that much... you will be sitting pretty for the DAT!**

How do sarcomeres shorten and contract a muscle?

The exact mechanism is not known, but we use a model called the sliding filament model to help rationalize things.

Muscle contraction will:

- 1) I bands shorten
- 2) H-zone shortens
- 3) A-bands do not change
- 4) Z-lines come closer together

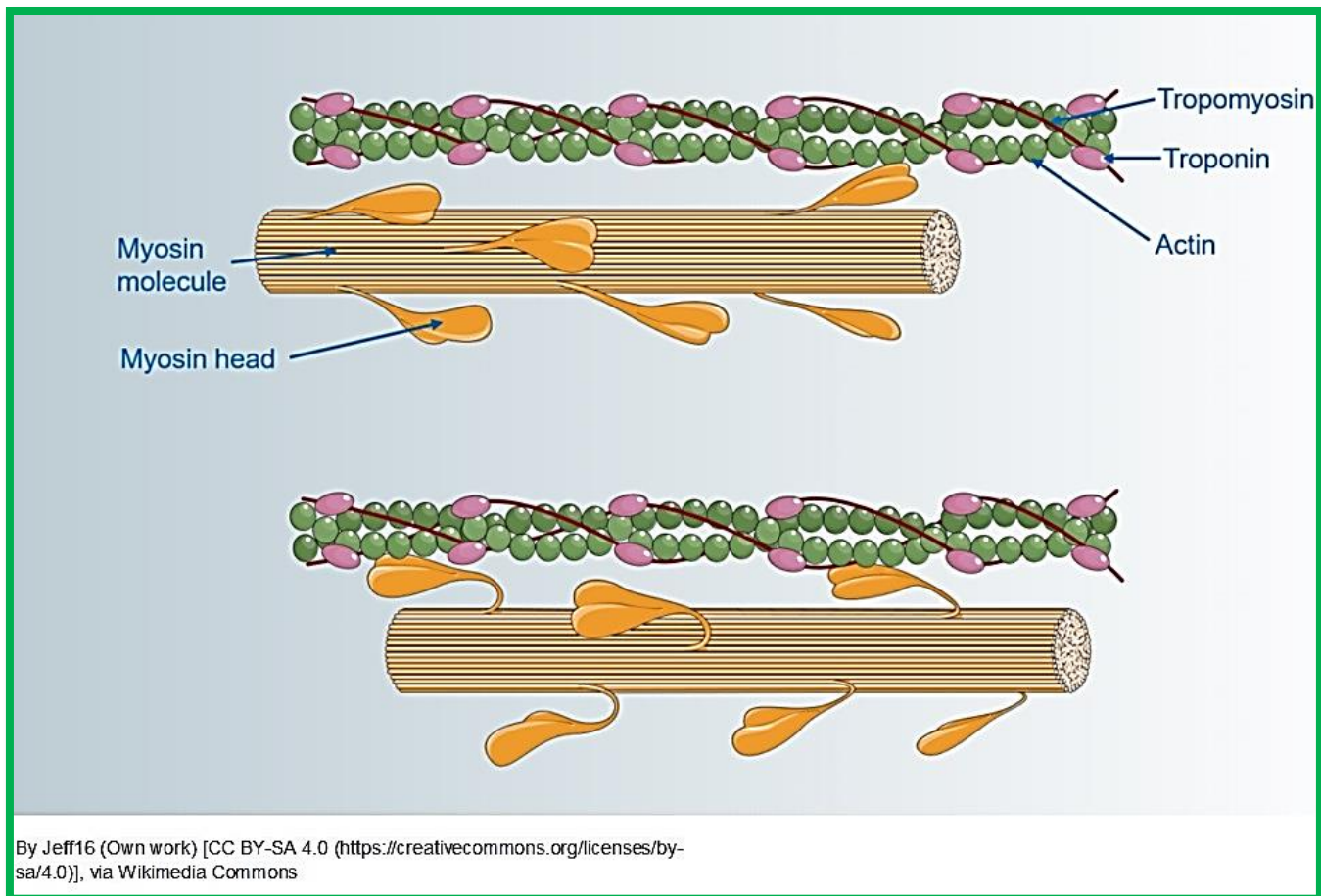
Chapter 28- Muscle

★ **Always a multiple choice-type question!**

Let us first consider **actin**:

Bound to the actin is:

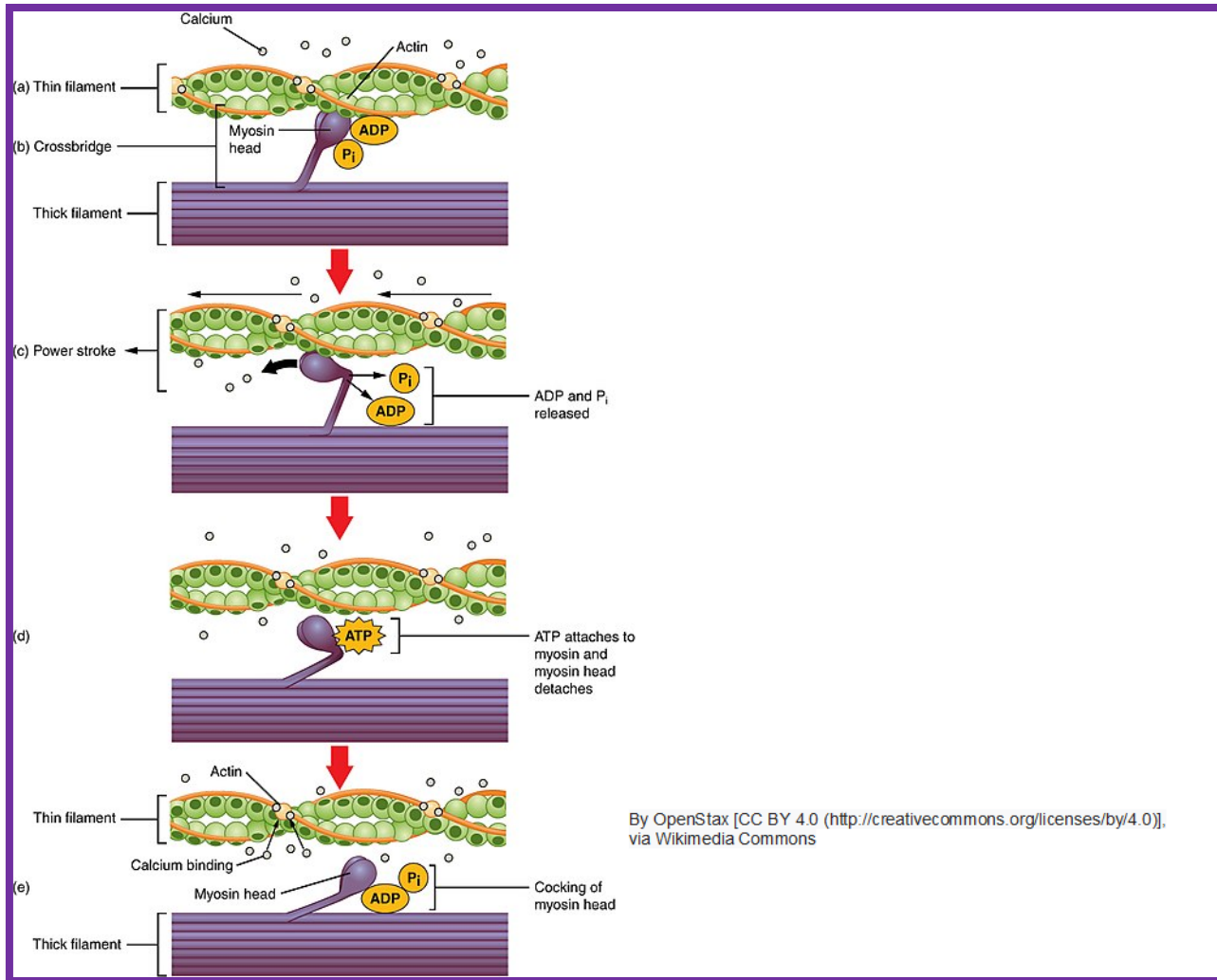
- 1) **Tropomyosin**: a regulatory protein
- 2) **Troponin Complex**: more proteins



Look closely at my picture and note that the tropomyosin covers the binding site for myosin to attach along this actin filament. Thus, the actin and the myosin cannot associate. Let's go through what occurs:

- 1) The story begins with the release of acetylcholine from the presynaptic nerve. The acetylcholine binds to the muscle fiber receptor and depolarization occurs. In other words, an impulse occurs and goes to the interior of the fiber via T tubules which is conveyed to the sarcoplasmic reticulum.
- 2) The sarcoplasmic reticulum releases Ca^{++} through voltage-gated Ca^{++} release channels and enter the cytosol to bind to troponin. **(A favorite DAT question!!)**
- 3) Upon binding to troponin, we see a change of shape. When this happens, it exposes the binding site for the myosin.

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- 4) The myosin heads bind to the nearby actin filaments...
- 5) Myosin heads tilt toward the center of the sarcomere sliding the actin filament with them. This is powered by ATP!!
- 6) ATP now binds to myosin head, causing it to release the “grip” on the actin. Hydrolysis of ATP returns the heads to the original position.

★ In **Rigor Mortis** following death (2-6 hours), the lack of ATP prevents the dissociation of actin and myosin, and we see a state of muscle contraction. In a few days, however, the rigidity of the corpse disappears because the muscle proteins decompose. The smell of a dead corpse is due to bacteria and enzymes breaking down body tissues. Many gases and compounds such as putrescine and cadaverine are produced when proteins decompose. Believe it or not, PhD papers are written on this stuff. Have a look!!

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A single contraction requires hundreds of these myosin heads performing a series of short strokes... we call them “power strokes”.

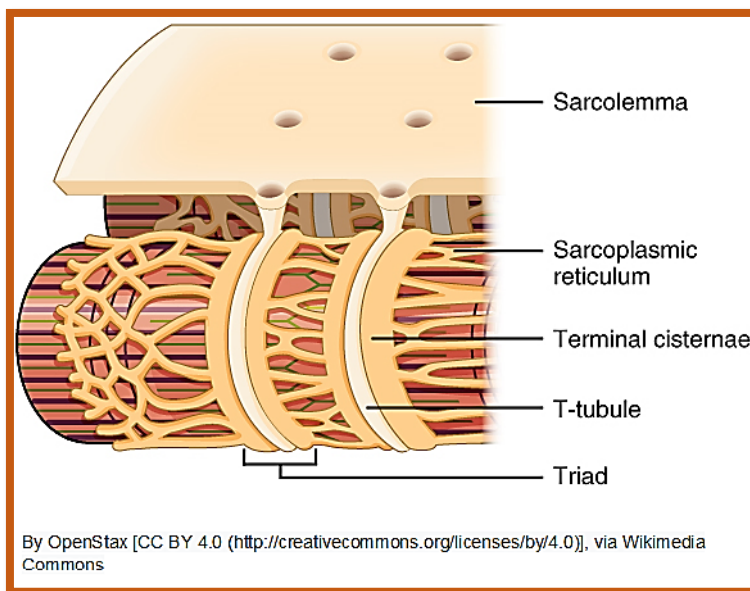
An average muscle fiber has a finite amount of ATP, thus if more ATP is needed, where does it come from?

Creatine Phosphate is able to donate a phosphate group to ADP to make additional ATP. A cell has about 5x more creatine phosphate than ATP.

During moderate exercise, the TCA cycle and electron transport chain, supply most of the ATP needed for muscle contraction.

Glycogen breakdown is needed to supply the needed glucose to burn. Once the glycogen is exhausted, fatty acids can be utilized. Recall that fatty acids can be oxidized into acetyl CoA, which can generate ATP using the TCA cycle and electron transport chain.

Recall that the sarcoplasmic reticulum contains the Ca^{++} . The muscle cell membrane is called the sarcolemma. Besides the sarcoplasmic reticulum, another set of membranes called T-tubules (Transverse Tubules) extend inward and pass all the way through the fiber. Each of these tubules opens to the outside of the muscle fiber and contains the extracellular fluid.



This specialized complex consisting of a T-Tubule and usually two small cisternae of sarcoplasmic reticulum is called the **triad**. When the membrane depolarizes Ca^{++} is released! When depolarization ends, Ca^{++} is transported back into the cisternae.

Recall the **motor unit**. This consists of a single motor neuron and all the muscle fibers it controls. All the muscle fibers move as a group during an action potential.

What does the strength of contraction depend on?

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It depends on the number of muscle fibers that the motor neuron controls. The strength of the contraction will be dictated by the number of motor units activated. If your brain recruits many motor neurons along with their motor units, you can lift an object that is quite heavy. This is called the process of **recruitment**.

By experimentally stimulating a motor unit with an electrical impulse, a scientist can cause an action potential. A recording is done of an isometric contraction. This means that the tension in the muscle develops, but it does not shorten.

This tension increases, peaks, and declines. This response is a **muscle twitch**. If a new stimulus is applied before a response ends, there will be **summation**, in which the contraction will be larger. Essentially, we simply added the two twitches together.

If the frequency of stimuli is increased further, individual contractions blend into a single, sustained, forceful contraction called a **tetanus**. A tetanus contraction continues until:

- a) The stimulus is removed
- b) The muscle gets fatigued

Let's generate a tetanus. Get a heavy box and hold it above your head for a few minutes. This is a tetanic contraction.

A tetanic contraction can take a few forms:

- a) **Isotonic:** muscle tension is constant; muscle shortens as it contracts
- b) **Isometric:** muscle generates tension; muscle does not change length

Have you ever lifted weights? We do a few reps (I love working 6 sets using 45 lbs in each hand for 10 reps) ... then our muscles begin to fatigue as lactic acid builds up and less O₂ is available to the muscle. What do we do?

The weights come down, and we rest a few minutes (a minute or two for me) between sets. After a few minutes, the fatigued muscle will be ready to contract again in response to stimulation.

Skeletal muscles are never completely relaxed, but have a slight sustained contraction called a tonus.

Tonus is maintained throughout our life and involves alternation of relaxation and contraction of the motor units with our muscles. Tonus produces no fatigue, however. Why? Because rest always follows a contraction.

If you are in class and falling asleep, your head suddenly jerks straight up. This is an unconscious reflex reaction made possible by the presence of muscle tone.

Your wonderful looking face is maintained by muscle tone. The loss of teeth can alter facial structure. Why? With the loss of teeth comes loss of bone. Which will lead to collapse of surrounding structures.

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What is a GTO?

This is the Golgi Tendon Organ. They are mechanoreceptors that are found at the junctions of muscles and tendons. Essentially, they monitor the force of muscle contraction. Understand that when a muscle undergoes a strenuous contraction, large forces can be generated. The GTO is very sensitive to increases in tension and aids in regulating the amount of effort needed to perform a movement that requires a variable amount of muscular force.



Types of Skeletal Systems

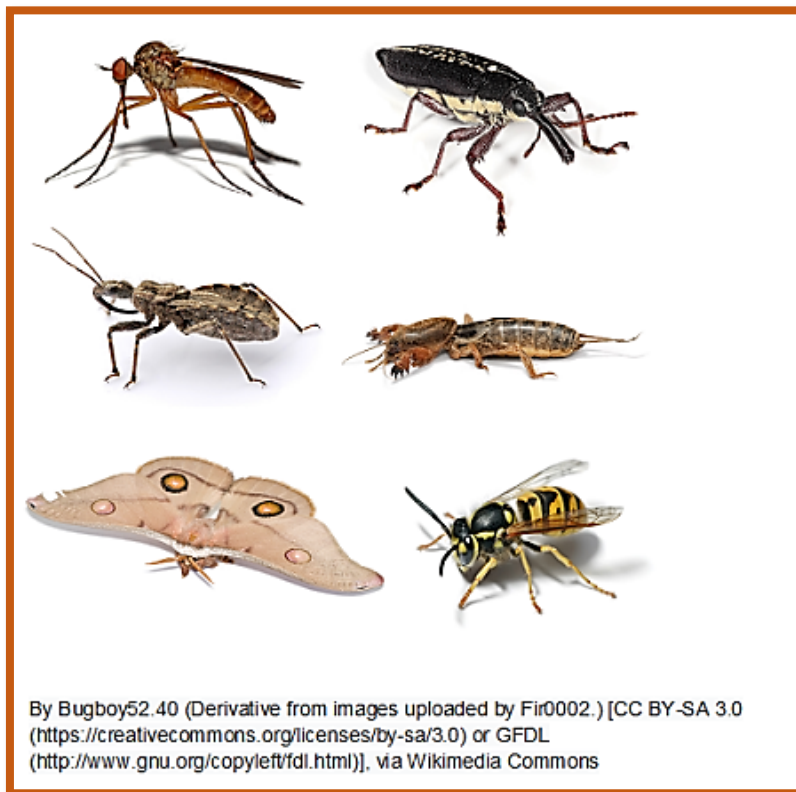
Hydrostatic:

Involves muscles and fluids

Seen in annelids, nematodes (round worms), cnidarians such as hydra and jelly fish, and Platyhelminthes (flatworms)

Muscles reused to generate a force that changes the shape of fluid-filled spaces.

Exoskeletons:



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Made of calcium carbonate (CaCO_3)

Encloses organisms such as mollusks

Arthropods have an exoskeleton composed of chitin... a polysaccharide comprised of a sugar contain nitrogen.

Endoskeletons:

Hard structures like bone, CaCO_3 , cartilage are found within soft tissues

e.g. echinoderms have ossicles beneath their skin. Ossicles provide rigidity and protection. Sea urchins, starfish, sea cucumbers contain these ossicles and are made of carbonates of calcium and magnesium.

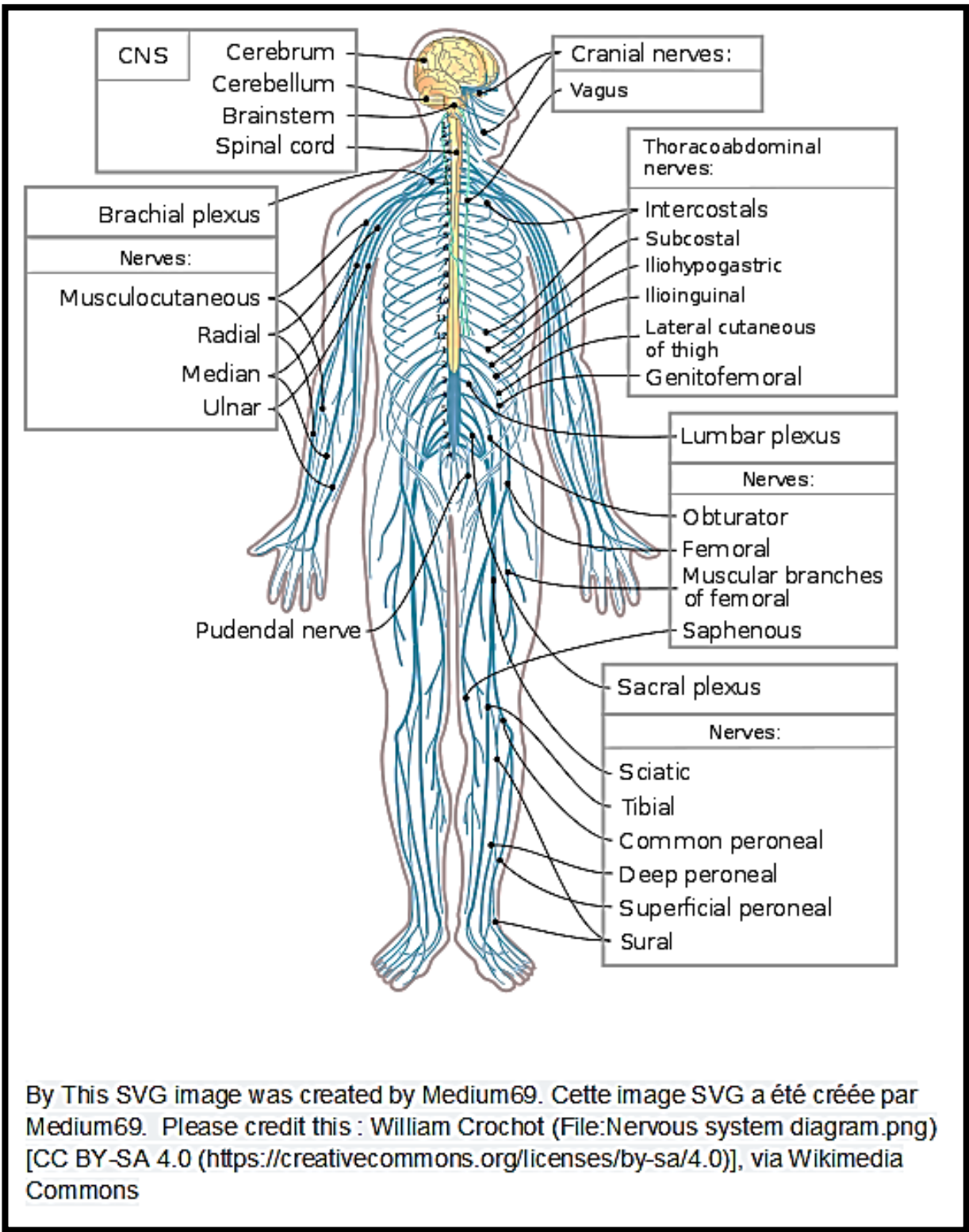
Chordates like us have an endoskeleton made of bone and cartilage.

Finally... worms move by muscles. If you look closely at each segment in a worm, you will see “small hairs” or bristles. They are called **setae**. The setae help the earthworm to attach to surfaces and help to anchor and control the worm as it moves through the soil. Thus: segmentation (100-150 segments) allows the earthworm to move (locomotion).



Chapter 29- The Nervous System

The Nervous System

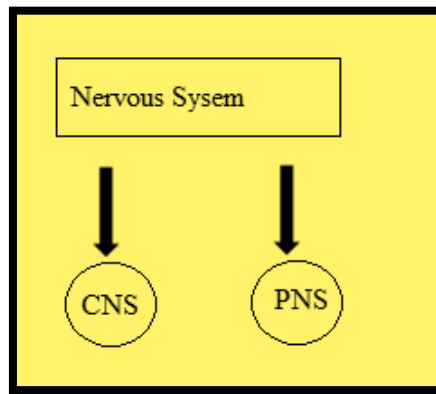


This system allows the organism to **sense and respond** to conditions inside and outside the body.

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This system develops

from the ectoderm of the embryo.



CNS= Central Nervous System: brain and spinal cord

PNS= Peripheral Nervous System: located outside the CNS, consists of cranial nerves, spinal nerves, and associated ganglia

A cranial nerve connects brain to organs mainly in the upper body or head (12 pairs) ★

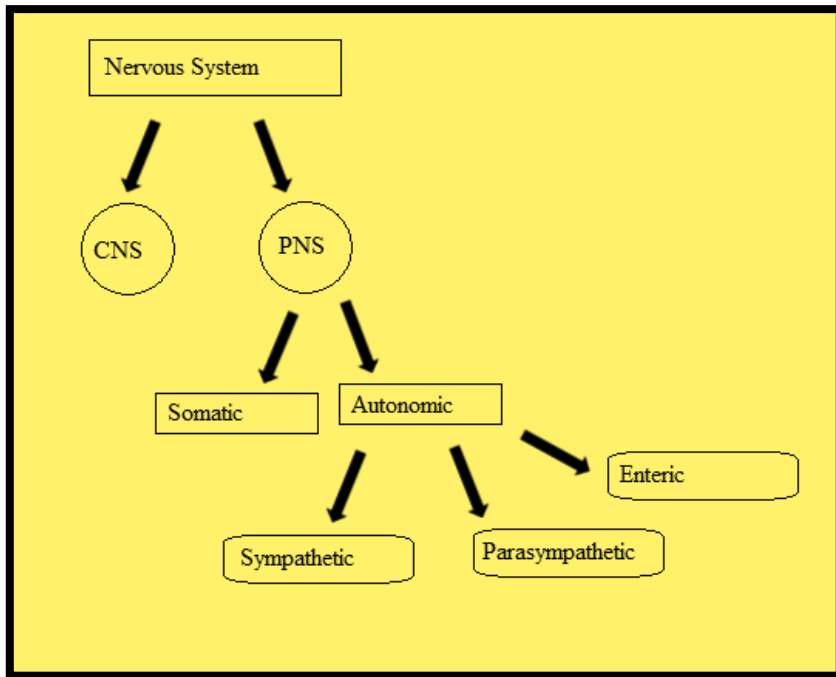
There are 31 pairs of spinal nerves... connects spinal cord to parts of the body below the head ★

Now, the PNS can be divided into:

- 1) **Somatic nervous system:** voluntary... will carry impulses to skeletal muscles, tendons, and skin
- 2) **Autonomic nervous system:** involuntary... impulses are transmitted to cardiac muscle, smooth muscle, or glands

Chapter 29- The Nervous System

To summarize:



Sympathetic: think energy generation... fight-or-flight

Parasympathetic: think calmness... rest-and-digest

Chapter 29- The Nervous System

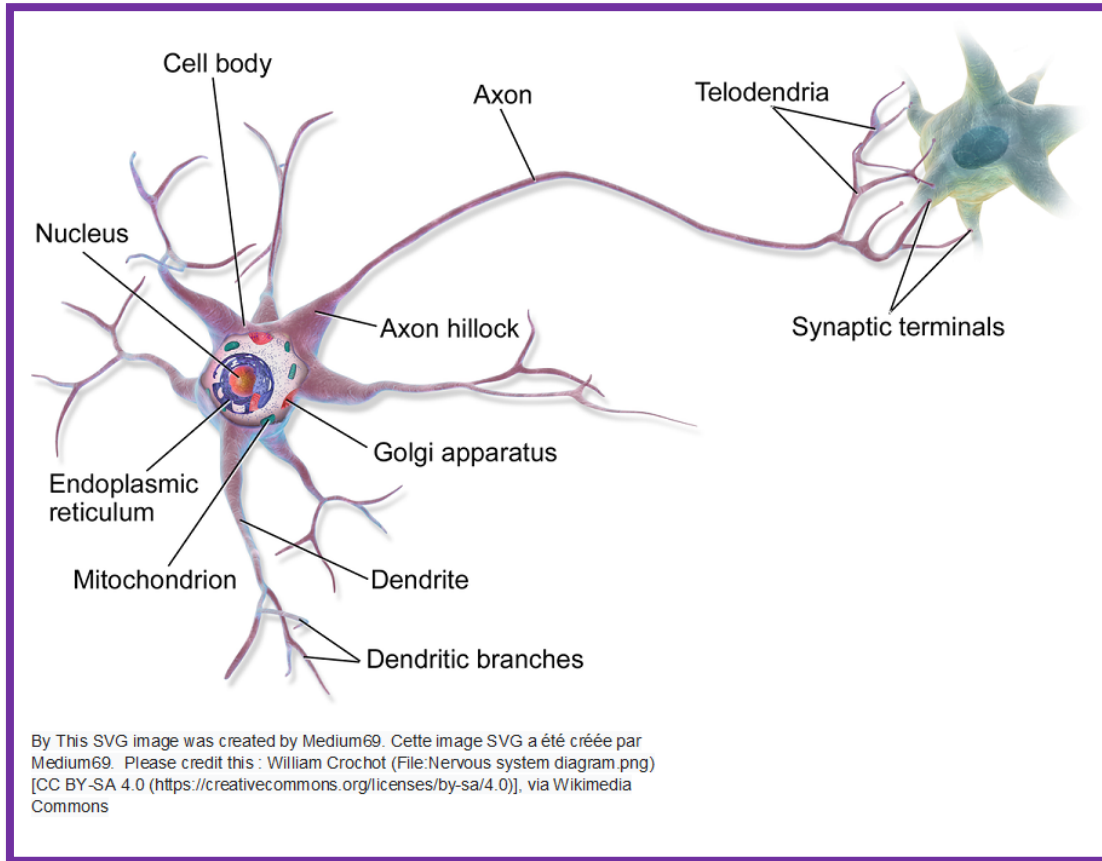
A few definitions:

Motor neuron (efferent): relays signals from the brain or spinal cord to muscle or gland cells

Sensory neuron (afferent): detracts information from the internal and external environment and transmits them to the CNS

Ganglion: a mass of neuron cell bodies usually found outside the CNS

Neuron: the basic unit of nervous tissue, it is a nerve cell including cell body, axon, and dendrites



★ According to the data that I have seen, 100 billion or more neurons are in the body!

They are so specialized, thus incapable of reproducing themselves. Replacing old neurons with new neurons would literally “erase” our memory away... thus no mitosis with these cells. Their ability for regeneration is very poor.

Each neuron contains a large nucleus and a number of organelles such as **Nissl bodies** (essentially nothing but rough endoplasmic reticulum in neurons), mitochondria, Golgi, lysosomes, ribosomes, etc. The brain contains glycogen, but at low concentration as compared to the liver and skeletal muscle. Cells called astrocytes contain glycogen. Much research is going on studying this.

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Glial cells: surround neurons and provide support and protection for them. Glial cells represent the most abundant cell in the CNS. They include astrocytes, oligodendrocytes, Schwann cells, microglia, satellite cells, and ependymal cells.

Axon: Extension of a neuron that carries nerve impulses away from the cell body to target cells such as nerve, muscle, or gland cells. No neuron has more than a single axon.

Dendrite: highly branched neuronal extensions that bring nerve impulses toward the cell body, also called the soma

★ Many mitochondria can be seen scattered in the cytoplasm of the soma, dendrites, and axon, but most abundant at the **axon terminals**. The axon terminals contain the neurotransmitters and get released at the **synapse**.

Astrocytes: Star shaped cells, most numerous glial cell. Many functions include regulating electrical impulses, provide neurons with lactate for nutrients, contain channels for K^+ transport, regulates blood flow, and even take part in neuronal repair.

Oligodendrocytes: makes myelin in the CNS

Schwann Cell: makes myelin in the PNS

Blood-Brain Barrier: high density cells (endothelial cells) that prevents the passage of substances such as pathogens, antibiotics, and chemicals. Some molecules such as CO_2 , O_2 , water, glucose, and amino acids can cross. Astrocytes have long been given credit for the creation of this barrier, but I have been reading conflicting data that suggest this might not be true.

Bottom Line: the blood brain barrier protects the brain from toxic substances and pathogens.

Multiple Sclerosis is considered an auto-immune disease. NMR data has shown a break-down of the blood brain barrier in a section of the CNS... allowing T-Lymphocytes to cross over and attack the myelin sheath. Thus, MS is also a disease of the blood-brain barrier.

In **epilepsy**, we see uncontrolled seizures. Studies have shown, there is blood brain barrier “failure” that leads to seizures.

Chapter 29- The Nervous System

Let us review the Autonomic Nervous System which includes:

- a) Sympathetic NS
- b) Parasympathetic NS
- c) Enteric NS

Sympathetic Division	Parasympathetic Division
Increases Heart Rate	Decreases Heart Rate
Increases Blood Pressure	Decreases Blood Pressure
Increases Respiration	
Increases blood flow to skeletal muscles	Decreases blood flow to skeletal muscles
Pupil dilation	Pupil constriction
Stimulates adrenal medulla (epinephrine and norepinephrine)	
Stimulates glycogenolysis	
Slowing for intestinal and stomach movements	Stimulates intestinal and stomach movements
Salivary gland secretion decreases	Salivary gland secretions increase
Decreases urine production	Increases urine production
Relaxes urinary bladder	Tenses urinary bladder
“Flight-or-flight”	“Rest and digest”

Know these for the DAT!!

Enteric Nervous System

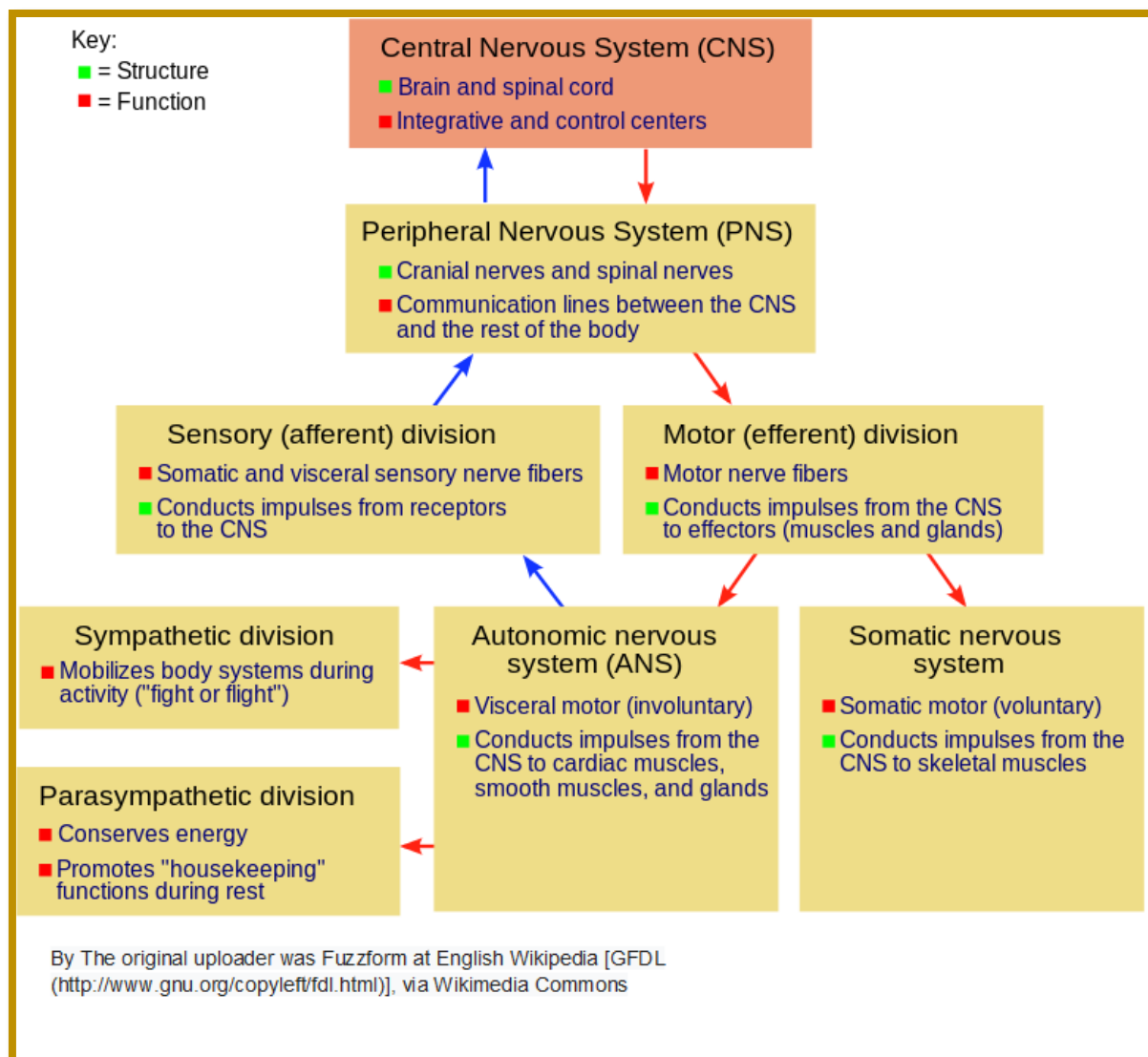
This extends the entire length of the alimentary tract... from the esophagus to the anus. It controls the secretory and motile functions of our digestive tract.

The older literature did not include this system as a division of the autonomic nervous system, but it has become added. The number of neurons associated with the enteric system is enormous. The gut contains 100 million neurons, more than even the spinal cord!!

The enteric nervous system has been called “The Second Brain”- it can work alone, independent of sympathetic and parasympathetic systems, but can work with them as well. This system makes over 30 neurotransmitters. 90% of our serotonin is made in the gastrointestinal tract, and a reasonable % of dopamine too!

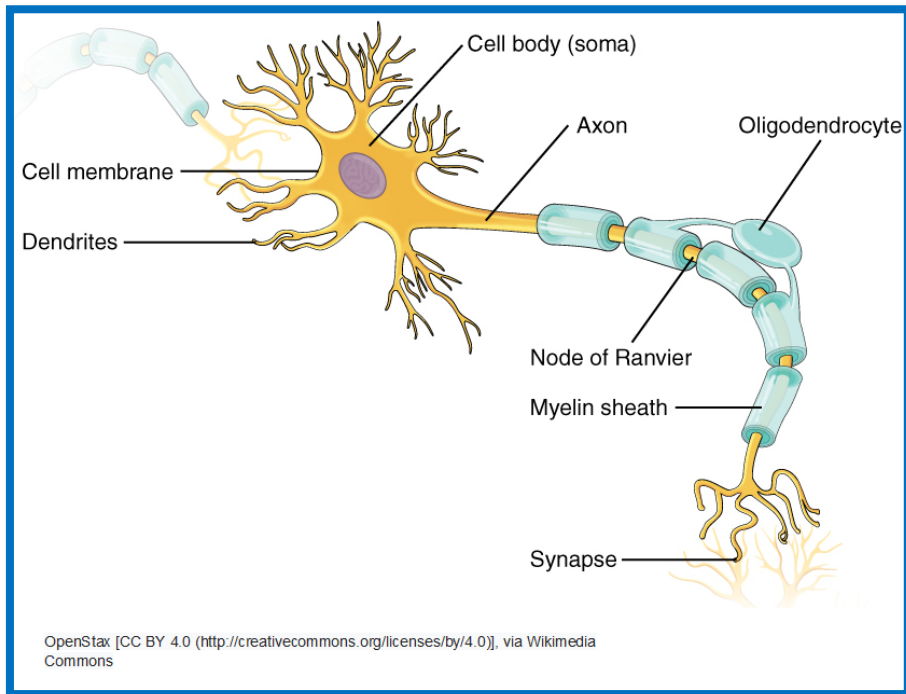
Much is still being learned about this highly complex system.

Chapter 29- The Nervous System



Chapter 29- The Nervous System

Myelin Sheath



Some axons are surrounded by a fatty substance forming an electrically insulating layer needed for proper functioning. This is called a myelin sheath. Myelin sheath contains cholesterol, lipids, and about 20% proteins. Myelin increases the speed at which the impulse moves along the myelinated fiber.

The CNS and PNS both have axons which contain myelin:

- In the CNS, the **oligodendrocytes** make myelin
- In the PNS, **Schwann cells** make myelin

Unmyelinated fibers will have slower impulse speeds.

In the brain:

- **Grey matter** consists mainly of unmyelinated axons
- **White matter** consists mainly of myelinated axons

The **axolemma** is the cell membrane surrounding an axon.

The **nodes of Ranvier** are the gaps between adjacent Schwann cells. At these nodes, the axolemma is especially permeable to Na^+ and K^+ . These nodes are only present when the axon is myelinated.

The action potentials can “jump” between these nodes in what is called **saltatory conduction**. In MS, the sheath is degraded and saltatory conduction cannot occur, thus transmission of the nerve impulse is slower.

Na^+ ion movement to depolarize the membrane can only occur at these nodes. It is at the nodes where we find the voltage-gated sodium ion channels.

Chapter 29- The Nervous System

Bottom line: these gaps are rich in ion channels!!

An impulse in myelinated fiber can move at 120 m/s; if unmyelinated fiber, less than 1 m/s.

Think of the myelin sheath as the plastic insulation that covers electrical wires.

The white matter of the brain is due to the groups of myelinated fibers.

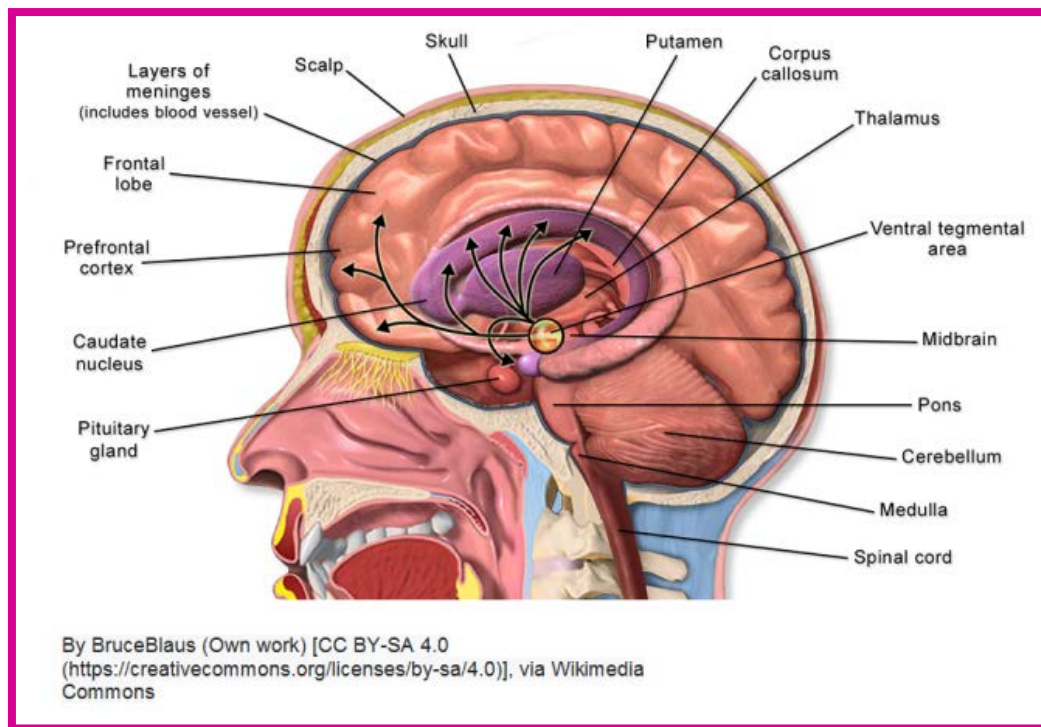
★ There are no Schwann cells in the CNS; oligodendrocytes form the myelin there!

Chapter 29- The Nervous System

Let us examine the **brain**

The DAT exam will ask you very general questions here, thus I will briefly go after the essentials. You will learn many exciting details in neuroanatomy.

The Cerebrum



Largest part of the mature brain (80% of our brain)

2 hemispheres are connected by a deep bridge of nerve fibers called the corpus callosum.

Each hemisphere has an outer covering of gray matter called the cerebral cortex. Gray matter contains cell bodies, glial cells, dendrites, and unmyelinated portions of axons.

Most of the brain's neuronal cell bodies are here. The gray matter includes regions of the brain involved with seeing, hearing, memory, speech, emotion, and decision making, among others.

To pack more gray matter into the small amount of space in our skulls, the cortex must be wrinkled. The surface is marked by ridges called convolutions or gyri, which are separated by groups.

- If the groove is shallow it is a **sulcus**
- If the groove is deep it is a **fissure**

The four lobes include: front, parietal, occipital, and temporal. Different functions are associated with each lobe. For example, the frontal lobe controls motor function, and the temporal lobe is associated with language. We need not concern ourselves with this here, however.

Chapter 29- The Nervous System

★ Some authors include limbic and insular with these, but I will stay with tradition and say 4.

Underneath the gray matter lies the **myelinated white matter**:

White matter connects various areas of gray matter to each other and carry impulses between neurons. Bundles of nerve fibers are called tracts. Tracts are used to describe the myelinated axons of the white matter.

Bottom line: white matter is a relay and communication region of the brain.

The corpus callosum is a white matter tract connecting the two brain hemispheres. It is the largest white matter structure in the brain.

In the deep white matter, we find basal ganglia (nuclei) and is involved with allowing us to feel the passage of time, and selecting of behaviors when dealing with decisions. Much is still unknown, however.

The meninges are three membranes that envelope the brain and spinal cord:

Dura mater: outermost layer... many nerves and blood vessels... tough and fibrous

Arachnoid mater: middle layer... no blood vessels, a thin, delicate layer

Pia mater: innermost layer, very vascular and intimately attached to brain and spinal cord

★ Between the arachnoid and pia mater is a subarachnoid space that contains the cerebral spinal fluid.

★ Inflammation of the meninges is called Meningitis and can be bacterial or viral. It usually will involve the arachnoid and pia maters.

★ Each brain hemisphere controls the opposite side of the body. If a brain tumor is located on the left side of your brain, the right arm or leg could become weak or paralyzed!

The Cerebellum

This part of the brain is involved with **balance and muscle coordination**.

If there is an injury to the cerebellum, fine movement, equilibrium, posture, and motor learning would all be affected.

The basal ganglia which includes the caudate nucleus, putamen, and globus pallidus work with the cerebellum to coordinate fine motor movements such as moving your fingertips.

The Hypothalamus

The link between the endocrine and the nervous system. **(A favorite test question from teachers!)**

The nervous system responds quicker, in general to stimuli than the endocrine system. Endocrine system secretes hormones that travel to target organs, while the nervous system uses neurotransmitters and action potentials to respond to stimuli.

The hypothalamus is part of what is called the **limbic system**. The limbic system deals with emotion, motivation, behavior, and is still not known with certainty.

Chapter 29- The Nervous System

The hypothalamus makes ADH and oxytocin as well as releasing hormones I discussed.

The hypothalamus is involved with a range of functions including fluid balance, blood pressure, body temperature, and maintaining homeostasis. The hypothalamus is also involved with emotions, sex drive, thirst, and even the production of digestive juices. Not a month goes by where I don't see another PhD paper written about the hypothalamus.

The main concept for the DAT exam is that it links both nervous and endocrine systems.

Besides the hypothalamus, the amygdala, hippocampus, and thalamus all make up this limbic system. This system is involved with emotions and plays a role in memory.

Long term memory seems to be associated with the hippocampus. We need not explore the others in any detail.

Medulla Oblongata

Helps regulate functions such as breathing, heart rate, swallowing, and digestion

The “center for respiration and circulation”

Involved in involuntary functions

Contains myelinated and nonmyelinated fibers

Cardiac, respiratory, and even sneezing and vomiting centers are located here.

Chemoreceptors can tell if the blood is acidic or not. Chemoreceptors send signals to the medulla which can respond with increasing the breathing rate, for example.

The **Agnathans** are the jawless fish. They include the **hagfish** and the **lampreys**- these fish possess a fully developed medulla. Thus, this part of the brain was very early to evolve. **(Make sure you know these two fish are from class Agnatha and were the first fish... you might thank me some day).** 😊

Thalamus

A “**relay station**” in the brain. It relays sensory information to the proper areas of the brain.

In **Tay-Sachs disease** we see neurons destroyed in the brain and spinal cord. This is an autosomal recessive disease in which a defect in a lysosomal enzyme is seen. This enzyme helps to break down a lipid in lysosomes. The enzyme is absent or present in reduced amounts. The ganglioside (a type of lipid) content of the brain of an infant with this disease is elevated. The disease is usually fatal before age 3.

The **cerebrospinal fluid** bathes, nourishes, and protects the brain and spinal cord from injury.

The **choroid plexus** is a network of cells that produce the cerebrospinal fluid in the ventricles of the brain. The plexus consists of cells called ependymal cells. The plexus also is involved with removing waste, excess neurotransmitter, and foreign substances from the cerebrospinal fluid. Four ventricles (interconnected cavities) are involved... within these cavities you will find the choroid plexus.

Chapter 29- The Nervous System

What are microglia?

These are phagocytic cells located in the CNS. They account for 5% of the glial cells.

What is a stroke?

Essentially, it is a “brain attack”... blood flow to an area of the brain is cut off and the deprivation of O₂ causes cell death.

Trouble with speaking, numbness of the arm, leg, or face, visual problems, headache, and trouble walking are all symptoms of a stroke.

A TIA or a, transient ischemic attack, is a mini stroke. It occurs when a clot or debris blocks the flow of blood to your brain.

Chapter 30- Nervous System Integration

Nervous System Integration

Three classes of Neurons

Sensory (afferent): closely associated with receptor cells; responds to external stimuli or internal conditions and relays them to brain and spinal cord

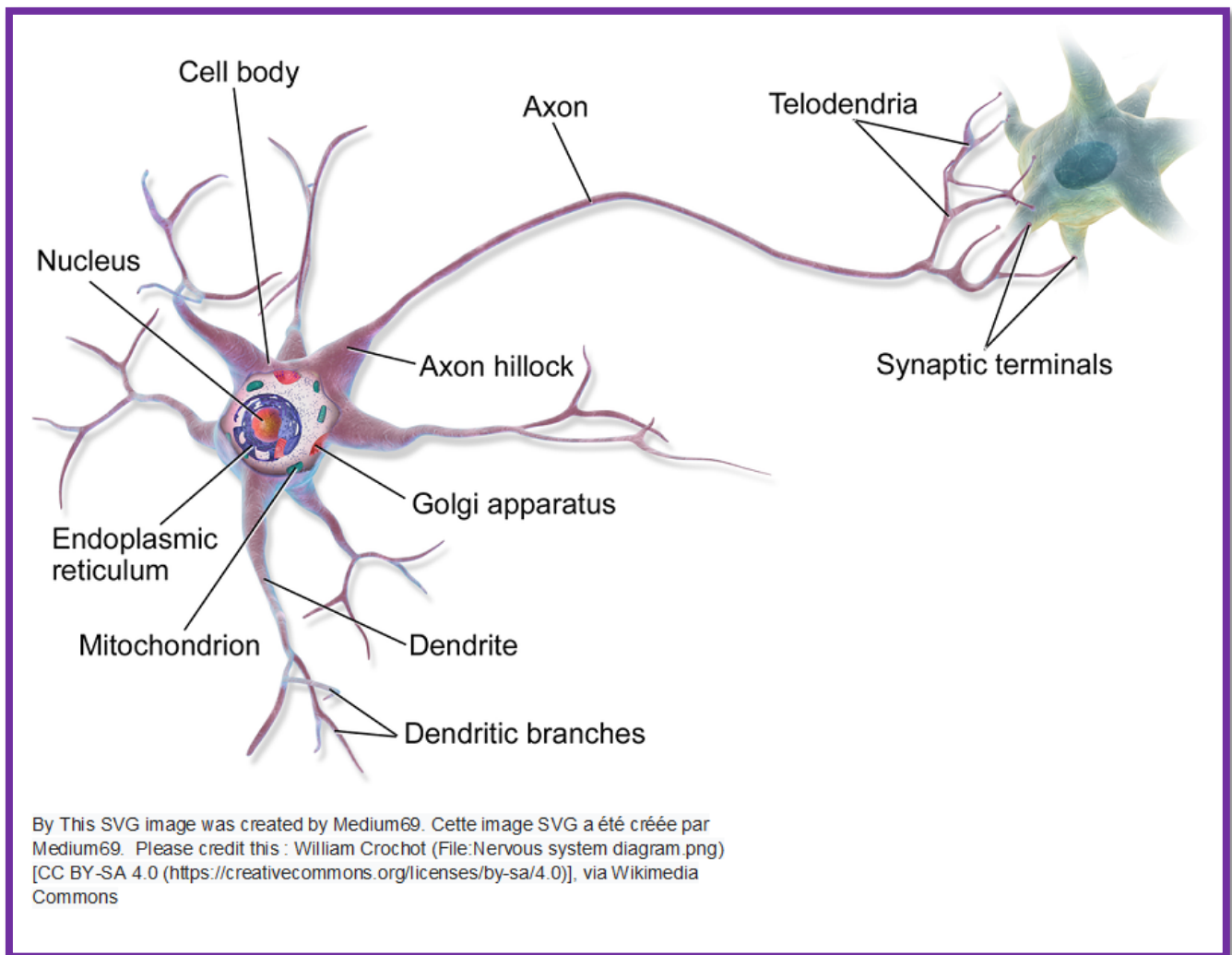
Interneuron: located between sensory and motor neuron; integrates sensory input and motor output

Motor (efferent): carry impulses out from the brain or spinal cord to effectors such as muscles or glands

★ Most nerves have both sensory and motor fibers and are called **mixed nerves**.

A few terms to know

Axon hillock: the part of the cell body that connects to the axon. This is where the action potential originates.



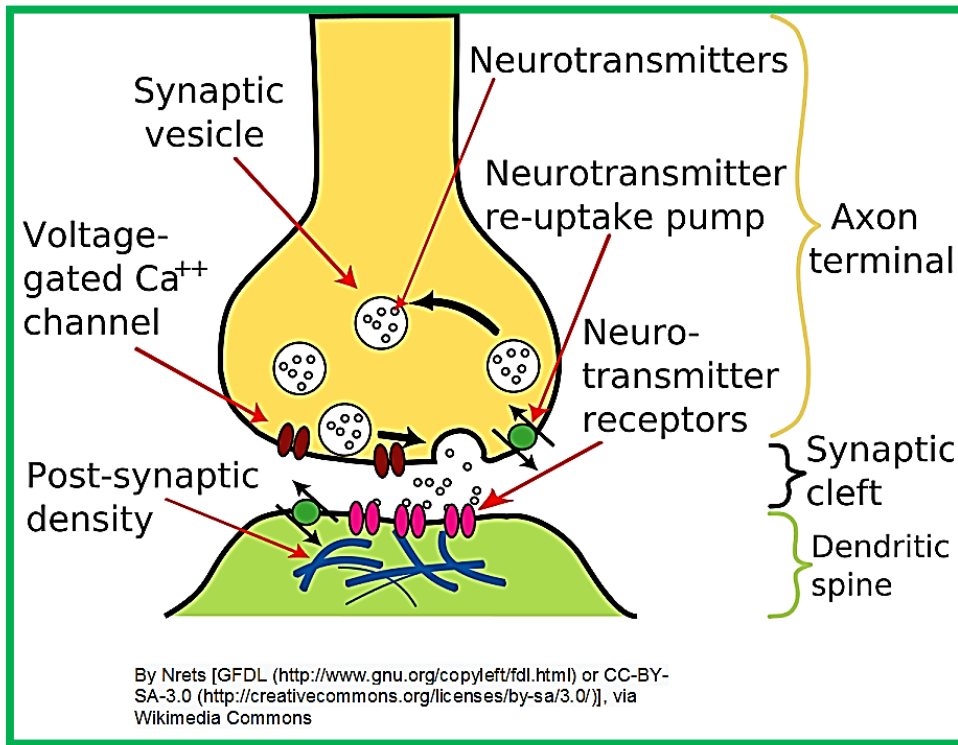
Chapter 30- Nervous System Integration

Synapse: represents the junction where one neuron communicates with another neuron. Neurotransmitters diffuse across here.

Presynaptic Cell: this cell stores the neurotransmitters such as acetylcholine stored in vesicles. Can be a muscle, neuron, or even a gland.

Postsynaptic Cell: the cell that has the receptors that bind to specific neurotransmitters

Synaptic Cleft: the gap between the presynaptic and postsynaptic membrane



As you can see, it is the presynaptic neuron that has vesicles that are filled with neurotransmitters.

All cells have voltage (membrane potential) across their plasma membrane. When a neuron is not stimulated (i.e. at rest) we see the inside is **negatively charged** with respect to the interstitial fluid on the outside.

The voltage or resting potential is about -70 mV.

$$[\text{K}^+]_{\text{inside}} > [\text{Na}^+]_{\text{inside}}$$

$$[\text{Na}^+]_{\text{outside}} > [\text{K}^+]_{\text{outside}}$$

Bottom Line: More K^+ is on the inside, while more Na^+ is on the outside.

These ion gradients are maintained by the $\text{Na}^+ - \text{K}^+$ pumps located in the plasma membrane and use ATP to actively transport Na^+ out of the cell, and K^+ into the cell. This pump helps to maintain the resting potential.

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(3Na^+ out; 2K^+ in). This allows for an excess of + charge outside the cell. Ion channels will allow ions to go back and forth, which could generate voltage or potential.

The resting potential is also maintained by the presence of large, negatively charged molecules such as proteins which are more abundant inside the neurons. Cl^- also reside more on the interior.

The Action Potential

This is a nerve impulse. It is **all-or-none**. A stimulus opens the voltage-gated Na^+ channels which cause Na^+ to flow into the neuron. This brings the potential to a positive value. As this occurs, we see a large change in the membrane voltage... this is an action potential.

Action potentials are essentially signals carrying information along the axon.

We have gone from -70mV to +40 mV for example. This is a **depolarization**.

What is a voltage-gated channel?

A class of transmembrane proteins that form channels that can open and close due to a voltage.

They are usually ion specific. For example, voltage-gated channels can be noted for:

a) Na^+ b) K^+ c) Ca^{++} d) Cl^-

Now, in order to generate an action potential, a certain value called the **threshold** must occur. Once this voltage is achieved, the neuron generates an action potential once it “fires”, the size of the action potential does not depend on the strength of the stimulus causing depolarization.

Bottom Line: If you don't reach the threshold potential, nothing happens. You must reach the threshold voltage... thus the action potential is all-or-nothing.

(Recall, we started at -70mV... a threshold for mammalian neurons is about -55mV).

Hundreds of action potentials can occur each second... the greater the stimulus, the more action potentials can be generated.

The cell membrane is unresponsive for a short time after an action potential has occurred. This is called the **refractory period**.

Remember: **speed is constant along the axon**... If you increase the stimulus, we generate more action potentials but the speed and amplitude (height) of the action potential will not change. Recall, having a myelin sheath will also allow for fast action potential generation along the axon. Myelin insulates the axon's membrane, and ion flow is restricted to the nodes of Ranvier. The impulse jumps from node to node by saltatory conduction.

The signal is conducted from the axon of a presynaptic cell to the dendrite of a postsynaptic cell. Communication occurs at special junctions called synapses... and the message is unidirectional... in that it can travel only one way.

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Presynaptic cell → Synaptic cleft → Postsynaptic cell

Thus:

The refractory period has two parts:

- 1) **Absolute Refractory period:** no stimulus, no matter how strong can elicit another action potential
- 2) **Relative Refractory period:** a very strong stimulus would be needed to elicit an action potential

(Dental injections prevent action potentials from occurring by blocking the Na^+ channels).

Ok... now what? We have just seen that depolarization has occurred, a voltage has been generated and is moving down the axon... now what?

First, let's talk about speed. The larger the diameter, the faster the impulse can move along the axon!

(Favorite exam question!)

The presynaptic neuron has vesicles that are filled with neurotransmitters. Gated channels for Ca^{++} are also present. As the action potential arrives, Ca^{++} voltage-gated channels open... allowing Ca^{++} to diffuse into the neuron. This Ca^{++} influx causes the synaptic vesicles to fuse with the presynaptic membrane. These vesicles dump their neurotransmitters into the synaptic cleft. The neurotransmitter can now bind to the receptor located on the postsynaptic cell's membrane. Binding will change the shape of the receptor... this allows a "passage" or entry area for ions to now cross. For example, the passage can allow Na^+ and K^+ ions to cross.

Neurotransmitters are eventually released from the receptors and can:

- 1) Diffuse away
- 2) Be broken down by enzymes
- 3) Be taken up by the synaptic terminal

Neurotransmitters can include such molecules as:

Acetylcholine: many functions including learning and memory enhancement

Dopamine: many functions including keeping focused and paying attention; promotes feelings of pleasure

Serotonin: depression can result if you have a deficiency!

Norepinephrine: involved with mental alertness and memory

GABA: body's inhibitory neurotransmitter. Keeps you calm and without anxiety. ★ Alcohol is thought to mimic the effect of GABA in the brain, decreasing anxiety and inhibitions.

Glycine: works with GABA to help decrease anxiety among other functions. Many have overlapping functions and is still being researched

Hopefully you can see that this is a very elaborate way by which neurons communicate with other cells.

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Norepinephrine is both a hormone and a neurotransmitter **(and is a commonly asked question)**.

★ The parasympathetic nervous system uses chiefly acetylcholine as its neurotransmitter. In the sympathetic nervous system recent research showed that both epinephrine and norepinephrine are used.

★ Dopamine is a catecholamine, like epinephrine and norepinephrine. Epinephrine, as well as norepinephrine, can function as a hormone and a neurotransmitter. There is some debate about classifying dopamine as a hormone, so I will keep it as a neurotransmitter.

Small peptide molecules can be used by nerve cells for communication. These molecules can bind to cell surface receptors and are called neuropeptides.

An example of a neuropeptide is substance P. This molecule is made up of 11 amino acids residues and is involved with pain and inflammation.

Endorphins are the natural body-analgesics that decrease our perception of pain. They are also neuropeptides. Besides decreasing our perception to pain, they may produce a euphoric or happy feeling in us. Laughing may indeed stimulate endorphins, as well as the “runners high” that occasionally is produced. (I have run 6 marathons, all under 4 hours and experienced a runner’s high at the Disney marathon of 2001. I ran it in 3:25:21 yay!).

Cnidaria



By Ed Bierman from Redwood City, USA (Sea Nettle) [CC BY 2.0 (<http://creativecommons.org/licenses/by/2.0>)], via Wikimedia Commons

Chapter 30- Nervous System Integration

Include hydra and a sea anemone contain a loose mesh of nerve cells called a nerve net. These nerve cells can interact with sensory and contractile cells.

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Arthropods



Have a small, but intricate nervous system that allows them to detect and respond to the world around them.

They possess a brain and a ventral nerve cord. In spite of the small size of an insect, many have axons with larger diameters than seen in humans... hence many insects are fast!!

Flatworms (Planaria)



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Do have a nerve net, but also has long nerve cords connected to cerebral ganglia in the head region. They have a bilateral nervous system on both sides!!

Earthworms have a brain as well as ganglia

Echinoderms (sea stars, sea urchins, sea cucumbers, sand dollars)

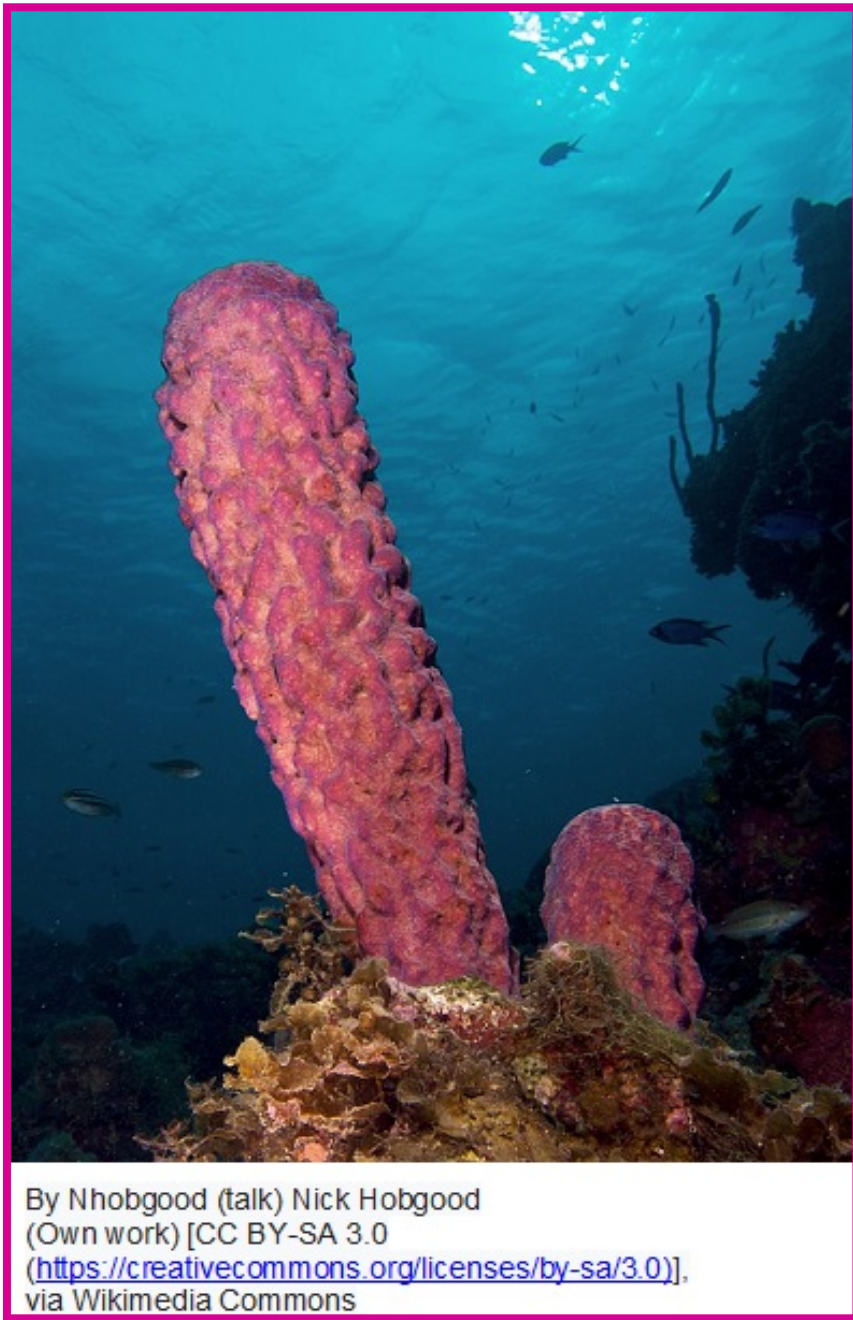
Do not have brains, but have nerves running from the mouth into each arm or along the body.

★ Recall these animals have radial symmetry and many have a CaCO_3 shell

They have a poorly developed respiratory system too, they use simple gills

Chapter 30- Nervous System Integration

Sponges



★ Are the only multicelled animal that lacks a nervous system!

No nerve or sensory cells

Scientists are still baffled by this, but in mid-2007, research showed that cells do communicate with each other. Proteins made by the sponge genes were found to interact with one another.

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Most sponges are hermaphrodites, they produce eggs and sperm from female as well as male reproductive structures.

Reflex

Are automatic, unconscious responses to certain stimuli

Helps to protect the body. For example, if you put your hand on a hot stove, you will very quickly pull your hand back long before pain and damage can occur.

The pathway involved is called a **reflex arc**.

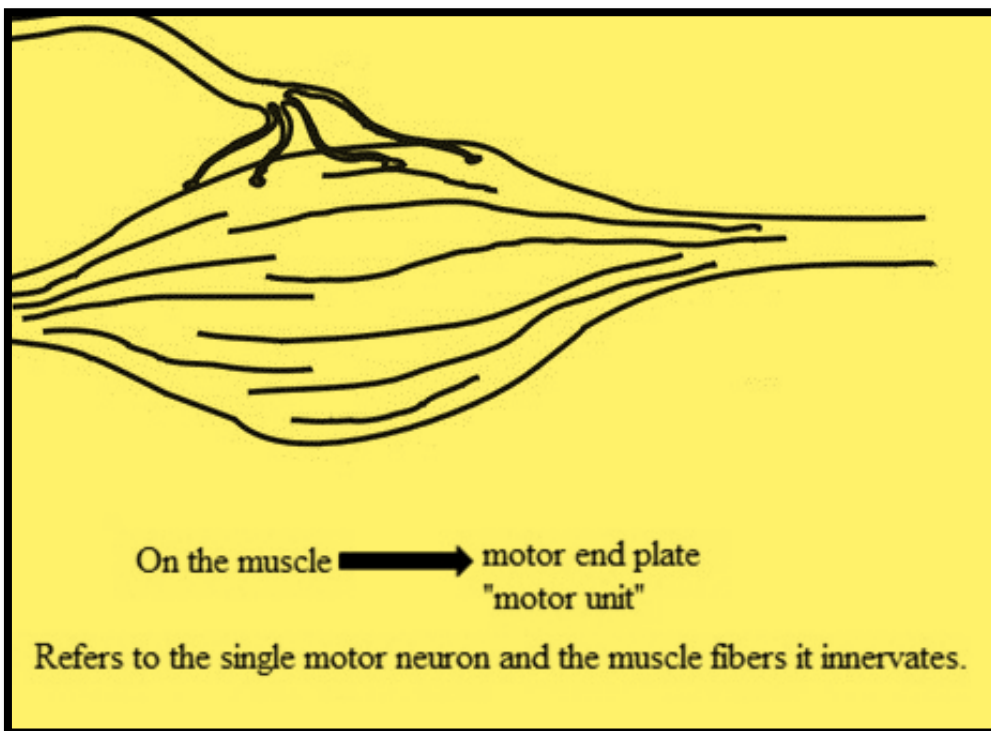
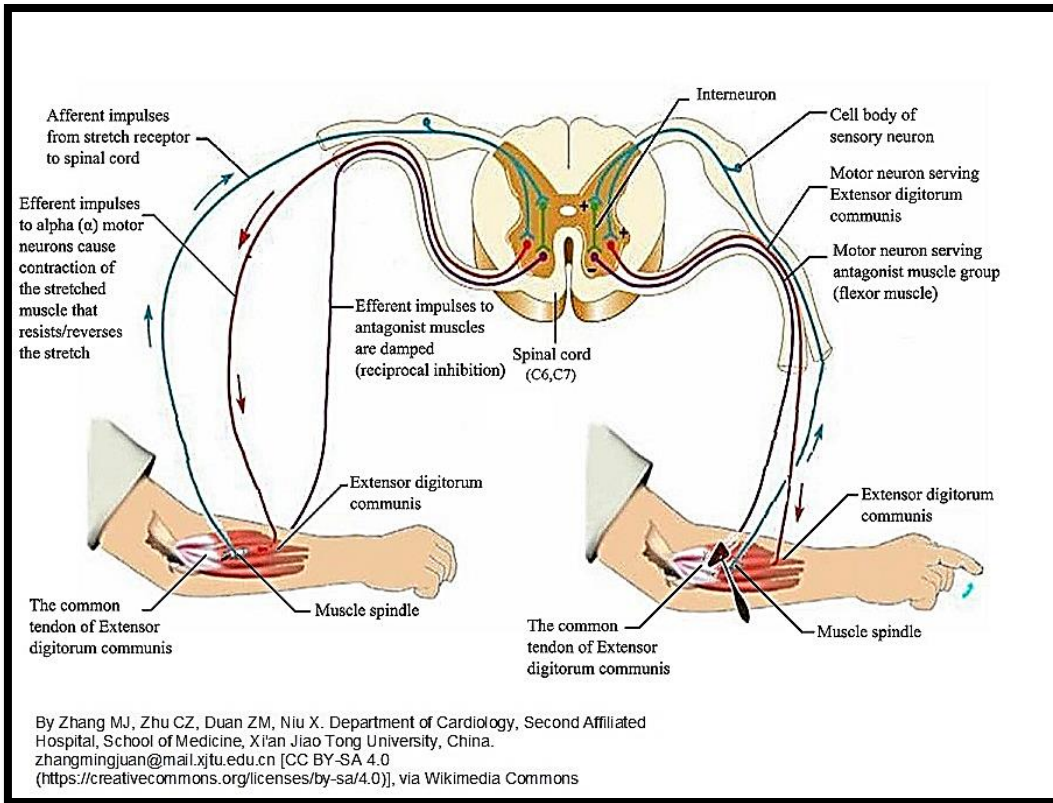
A reflex arc involves:

- a) **Receptor**... e.g. dendrite
- b) **Sensory neuron**... relays impulse to CNS
- c) **Reflex center** (composed of interneurons) ... arc is made
- d) **Motor neuron**... conducts impulse to the effector
- e) **Effector**... a muscle or gland

For example, you touch a hot stove... pain receptors in the skin are stimulated and the message is sent to the sensory neuron. The message is then sent to the spinal cord... no conscious decision by the brain is needed...there at the reflex center the interneurons transmit impulses to the motor neuron, and then to the muscles (effector). The muscles contract and you withdraw your hand.

I hope this gives you a reasonable idea of what is involved with this reflex arc.

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Spinal Cord

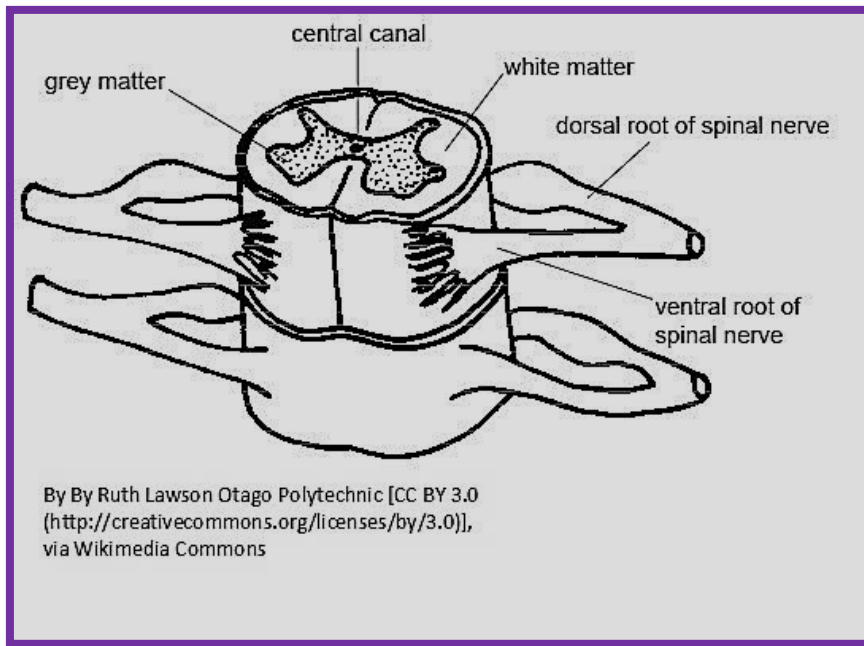
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Gray Matter (Neurons found here): looks like a butterfly

White Matter (Axons found here): contains the spinal tracts, sensory and motor

A spinal cord has 2 “roots” which emerge:

- a) **Dorsal root:** transmits sensory information “sensory root”
- b) **Ventral root:** this is the “motor root” and it carries information towards the limbs and organs



★ **Know the names Dorsal (sensory) and Ventral (motor) for the DAT!!!**

A few final points

Recall that if in response to a stimulus, the membrane potential becomes less negative, we call this a depolarization.

If the resting potential became more negative, we call this hyperpolarization.

We need to know the difference for the DAT exam. Recall, when Na^+ channels opened, some moved inward during depolarization.

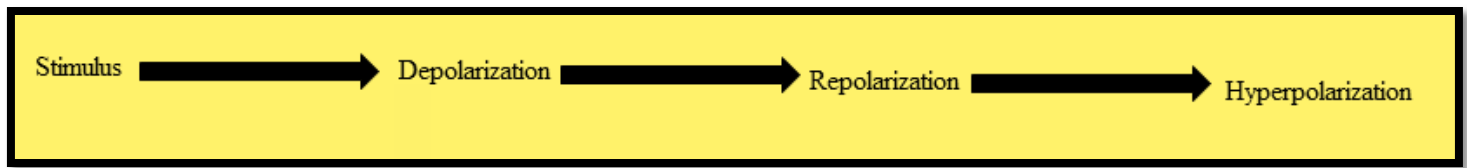
If potassium, K^+ , channels open, potassium ions would diffuse outward. Hyperpolarization is often caused by:

- 1) K^+ move out
- 2) Cl^- move in

Hyperpolarization acts to inhibit action potentials. Thus, after the peak of the action potential, a hyperpolarization repolarizes the membrane potential to its resting value. Hyperpolarization prevents the neuron from receiving another stimulus or at least raises the threshold for any new stimulus.

After hyperpolarization, we eventually re-establish the -70mV resting potential.

Chapter 30- Nervous System Integration



EPSP's and IPSP's

Let EPSP = Excitatory Postsynaptic Potential

Let IPSP = Inhibitory Postsynaptic Potential

Consider acetylcholine binding to its postsynaptic membrane receptor. If depolarization occurs, recall that an action potential was generated. It is excitatory, since the potential change favored the initiation of an action potential. However, not every event is excitatory (EPSP), where we see an increase in permeability of the postsynaptic membrane for Na^+ . If we see an increase in K^+ and Cl^- we get an IPSP or inhibitory postsynaptic potential and instead of getting a depolarization, we get a hyperpolarization.

Recall, as I pointed out, **hyperpolarization does not generate any action potential**. It keeps the neuron “lazy” or we say it has been inhibited.

Most neurons in the CNS have both excitatory and inhibitory synapses.

Bottom line: Neurotransmitters can be excitatory or can be inhibitory.

If many EPSP's have been generated at the same synapse by a series of action potentials on the presynaptic neuron, we call it temporal summation. It is an additive effect. If EPSP's produced nearly simultaneously by different synapses on the postsynaptic neuron, we call it spatial summation.

Temporal Summation: involves single synapse- ESPS's occur one after another

Spatial Summation: involves multiple synapses- ESPS's occur at the same time

Summation also applies to IPSP's:

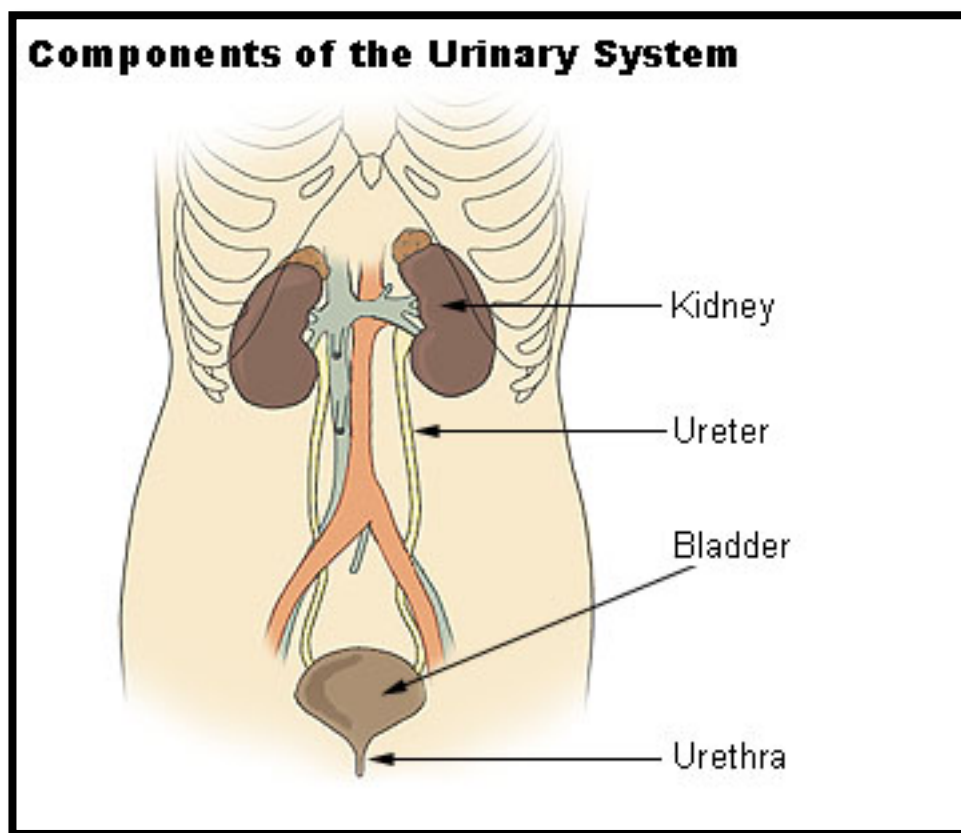
It is possible through summation that an IPSP can negate the effect of an EPSP.

This relationship between inhibitory vs. excitatory is the very essence of nervous system integration.

The axon hillock is the “integrating center” if the “sum” allows for an action potential, one will be generated.

Chapter 31- The Excretory System

The Excretory System



I have been studying science for many decades, and the kidney is by far the most complex of all body systems next to the brain, in my opinion.

The **DAT or the OAT exam will be asking you very general questions on this area**, so I will do my best to take a very complicated area and make it manageable for you.

A pair of kidneys lie at the back of the abdominal cavity. Each kidney is connected to a structure called a **ureter**. This duct will be responsible for carrying the urine to the **urinary bladder**, where it is stored until voided (you pee) from the body through the **urethra**. Sphincter muscles regulate micturition.

The kidneys receive blood from the **renal artery** and blood leaves through the **renal vein**.

There are two distinct regions:

Outer kidney = cortex

Inner kidney = medulla

The urinary system must remove toxic by-products of metabolism from the bloodstream, thus the kidneys are absolutely essential. Most students clearly see this.

The urinary system has another function which many of you overlook: salts, glucose, proteins, ions and water must be conserved or reabsorbed back to the body. Before it is urine, it is called **glomerular**

Chapter 31- The Excretory System

filtrate. The glomerular filtrate contains many things such as urea, amino acids, water, salts, glucose, and ions.

★ Glomerular filtrate contains the same substances as blood plasma, except for the larger proteins which the filtrate lacks. **(This is a favorite DAT question).**

About 1.5 L of urine are produced each day.

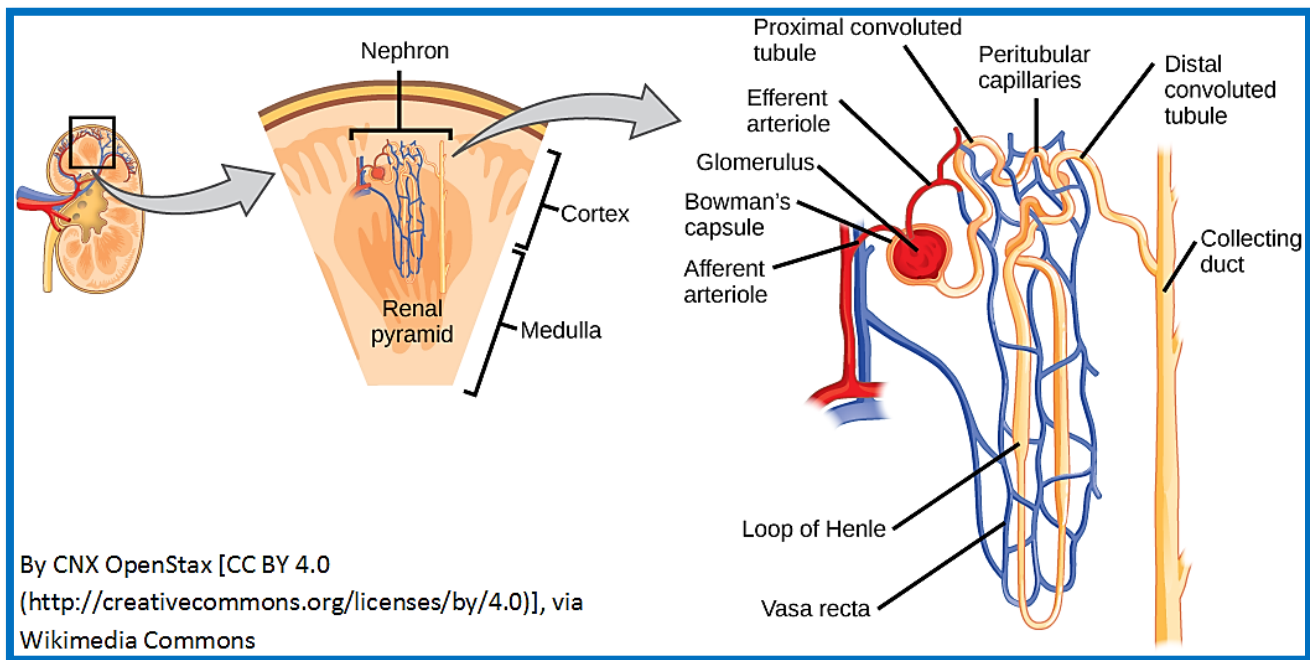
The kidneys make two hormones you need to know...

1. **EPO (erythropoietin):** stimulates red blood cell production
2. **Renin:** Involved with regulating blood pressure

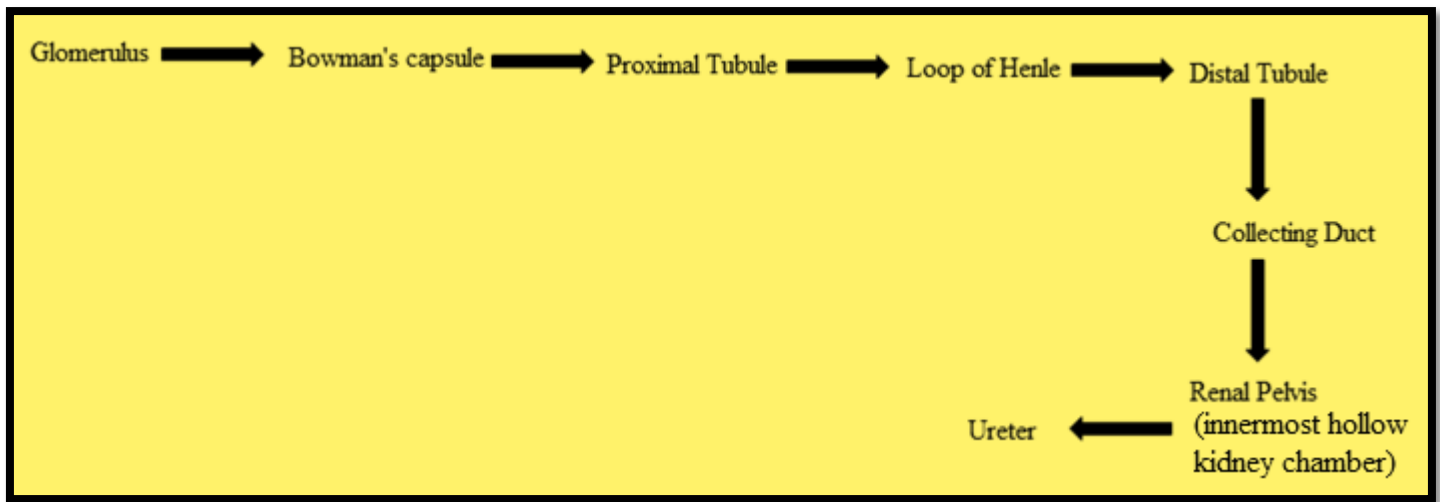
All the blood in our body passes through the kidneys every five minutes!

The functional unit of the kidney is called a **nephron**, and each kidney contains about 1 million of them. Human nephrons are similar to the earthworms' **nephridia** in that they are closely associated with capillaries.

Each nephron originates in the cortex, and has an expanded, hollow end called the **Bowman's capsule**. Enclosed within this capsule is a knot of capillaries called the glomerulus. **The remainder of the nephron consists of the regions you need to know and the exact order:**



Chapter 31- The Excretory System



The filtrate path will be:

Commonly asked exam question. Know the order of this path.

Bottom Line: Before it becomes urine, we must filter the blood and reabsorb the “good stuff” like glucose and excrete waste products such as urea.

Afferent arterioles supply blood to the glomerulus (tuft of capillaries), while the **efferent arterioles** provides the path for blood to leave the glomerulus.

Four processes will occur in the excretory system:

- 1) Filtration
- 2) Reabsorption
- 3) Secretion
- 4) Excretion

Note: there are four steps in the forming of urine!

Hydrostatic pressure (blood pressure) drives **filtration** which occurs in the **glomerulus**.

The glomerulus is well-suited for filtration since it has a large surface area due to the great number of capillaries. These capillary walls are more permeable than most capillaries to H₂O, small solutes, and ions.

Here is the most important point: H₂O, small solute molecules, and ions, pass selectively through the glomerular capillary walls but large molecules such as plasma proteins cannot pass.

These large molecules are held back and put back into the blood. The rest of the molecules can move on in what is called glomerular filtration. Blood pressure pushes the fluid (glomerular filtrate) out of the glomerulus into the **Bowman's capsule**.

We are now in Bowman's capsule. No big molecules allowed in!! Who is here?

Chapter 31- The Excretory System

Ions, glucose, amino acids, small solute molecules, nitrogenous wastes like urea, vitamins, and salts

Bowman's capsule contains cells called podocytes which are involved with filtering. Podocytes have long tentacle-like extensions.

From the Bowman's capsule, the glomerular filtrate moves to the **proximal convoluted tubule** or PCT, for short. Keep in mind that we must reabsorb water, ions, and nutrients from this filtrate.

★ **Most of the reabsorption takes place in the proximal convoluted tubule, and they are packed with mitochondria!!**

Glucose, amino acids, ions (like Na^+ , K^+ , Ca^{++} , HCO_3^- , etc.), must be reabsorbed. This is vital because as 75% of Na^+ goes out by active transport ($\text{Na}^+ - \text{K}^+$ ATPase pump), Cl^- follows because of charge attraction (a passive transport), and water follows by osmosis. The glucose, drugs, amino acids, or other ions and essential nutrients are transported out of the proximal tubule by active transport to the interstitial fluid and then into the peritubular capillaries. Normally, 100% of the glucose is reabsorbed in the proximal tubule unless there is beyond 200 mg/100ml or so. If this is the case, some would pass out in the urine. You would need to take a lot of sugar for this to occur. For those with diabetes mellitus, significant amounts of glucose are found in the urine. The kidney has a threshold for substances that it reabsorbs and are carefully monitored. If the plasma concentrations get too high, the excess is excreted in the urine. Blood content is highly regulated to maintain homeostasis.

Cells of the proximal tubule reabsorb about 65% of the water filtered along with almost all small plasma proteins and vitamins. In the proximal convoluted tubule, we see H^+ combining with NH_3 to make NH_4^+ . The buffering action of NH_3 helps remove some H^+ ions. HCO_3^- is reabsorbed as well. The pH is balanced.

★ Urea is only partly reabsorbed, but at a much slower rate than ions of H_3O^+ .

From this point, we must have the materials to be excreted to become concentrated.

Off to the **descending loop of Henle** we go!!

H_2O continues to be reabsorbed!! Aquaporins in this region allow for the descending loop of Henle to be very permeable to water!! The descending loop of Henle has a low permeability to salt, thus as the filtrate descends the loop, the urine becomes more concentrated.

Now we are at the bottom of loop and go upward to the **ascending loop of Henle**.

NaCl moves outward, but no H_2O moves since this ascending loop is impermeable to H_2O . The fluid goes from hypertonic in the descending limb to hypotonic in the ascending limb. As a result of losing NaCl , but not H_2O the glomerular filtrate begins to get more dilute as it ascends upward.

Now what? The ascending loop is straight, but suddenly twists as we encounter the **distal convoluted tubule**. The fluid reaching the distal convoluted tubule is not very salty, it is hypoosmotic to normal body fluids. The distal tubule is involved with **secretion**. K^+ , H^+ , and NH_4^+ ions are secreted. Like the proximal convoluted tubule, the distal convoluted tubules help regulate the pH.

Chapter 31- The Excretory System

★ The rate of Na^+ absorption and K^+ secretion by sodium pumps are regulated by the hormone aldosterone. The distal convoluted tubule is also high in mitochondria, but not as much as the proximal convoluted tubule.

A specialized structure formed by the distal convoluted tubule and afferent arteriole is called the **Juxtaglomerular Apparatus**. We need not go into the details, but it is involved with regulating blood pressure and filtration rate of the glomerulus. If blood pressure drops, blood volume drops. Certain juxtaglomerular cells produce **renin**, these cells are considered myoendocrine cells. These cells are endocrine, but also contain contractile tissue fibers.

Renin converts angiotensinogen into angiotensin I. Angiotensin I converts to angiotensin II. It is angiotensin II that constricts the blood vessels. Ultimately, this leads to an increase in the blood pressure. The juxtaglomerular apparatus cells also release Renin when cells from an area called the macula densa (of the distal tubule region) senses changes in Na^+ concentration. Angiotensin II also stimulates increased aldosterone secretion, thereby allowing more Na^+ and H_2O reabsorption.

We now move the filtrate to the **collecting duct**. When the kidneys need to conserve more water, water can move out by osmosis thereby concentrating the solutes including urea left in the filtrate. In the presence of ADH, the water can leave the collecting duct and be conserved for the body to use. The urine becomes hypertonic in the presence of ADH.

★ Alcohol decreases the ADH levels, thus water is not returned, but you end up urinating more!

The cells of the collecting duct are not only permeable to H_2O , but to some urea as well, under the influence of ADH (vasopressin).

Bottom Line: ADH regulates water balance. It increases the permeability of the collecting tubule to water and some urea (some is excreted, some is reabsorbed). This gives a urine that is more concentrated and a reduced water loss from the body.

After being formed, the urine passes to the **renal pelvis** and is conveyed by the **ureter** to the **urinary bladder**. It is excreted by means of the opening to the outside body called the **urethra**.

In the Destroyer book, there is a question about an animal called the kangaroo rat. It drinks very little water and thrives in the desert regions, such as Death Valley. The animal eats dry seeds high in carbohydrate and low in protein. Oxidation of the fatty seeds produces metabolic water.

In addition, exceptionally long loops of Henle are displayed. **The longer the loops, the more the urine can be concentrated**. Thus, most of the water is reabsorbed and only a small percent is excreted. Longer loop means more water is reabsorbed!!

A diuretic makes you increase urination rate by:

a) Decreasing permeability of collecting ducts

Or

b) Decreasing ADH production

Coffee, tea, and alcohol are all diuretics.

Chapter 31- The Excretory System

The urine composition is about 95% water; urea (from amino acid metabolism), uric acid (from nucleic acid metabolism), creatine (from metabolism of creatine) are also found.

Control Points (know this for the DAT/OAT!!)

The rate of glomerular filtration is directly proportional to filtration pressure.

The **afferent arteriole** is under **sympathetic nervous system control**. If the afferent arteriole becomes constricted:

- a) Glomerular hydrostatic pressure decreases
- b) Filtration rate decreases
- c) Volume of urine flow decreases thus urine output decreases

If **efferent arteriole** is constricted blood cannot flow past the constriction and blood backs up into the glomerulus:

- a) Glomerular hydrostatic pressure now increases
- b) Filtration rate increases
- c) Urine output increases
- d) Potential urine output increases

Hopefully, you can see this is a very complicated process... but we did it! We essentially reabsorbed needed nutrients, ions, and H₂O from the glomerular filtrate and formed urine. Renin, angiotensin, and aldosterone were our “salt-trio” who controlled how much sodium was reabsorbed.

What is the pH of urine?

Unfortunately, there is no exact value. Depending on factors such as diet, it can be a bit under 7 or a bit over 7.

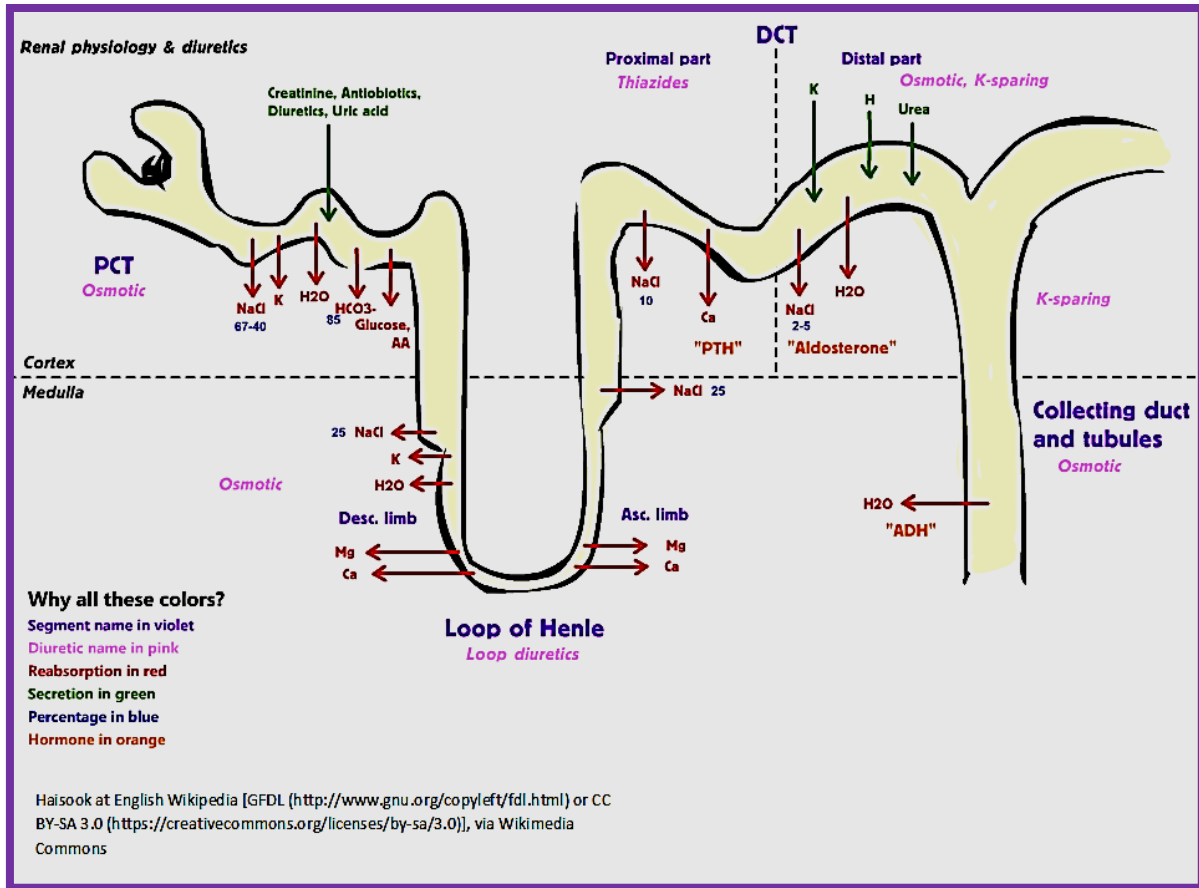
Micturition: process by which urine is expelled

As the bladder fills with urine, stretch receptors are stimulated and the need to urinate occurs. The micturition reflex center is located in the spinal cord.

There is a recycling of sodium chloride that permits the kidney to maintain a salty environment in the interstitial fluid at the bottom of the loop of Henle. There is what is called a **counter-current mechanism**. Recall, that H₂O leaves the descending loop of Henle, and little NaCl leave. The ascending loop of Henle is impermeable to H₂O, but pumps out NaCl. The Na⁺ and Cl⁻ ions from the ascending loop, circle around and return to the descending loop. Adding Na⁺ and Cl⁻ to it. Each time this circuit is completed, the concentration of NaCl increases or multiplies. For this reason, we call it a **countercurrent multiplier**.

Bottom Line: The NaCl gradient is produced. As we get down further in the loop of Henle, urine is concentrated more.

Chapter 31- The Excretory System



Chapter 31- The Excretory System

Nitrogenous wastes

Birds, Reptiles, Insects, and land snails: Uric acid

The main excretory structure of insects is the **Malpighian tubule (i.e. the grasshopper)**

Mammals and Mature Amphibians: urea

Aquatic Animals: ammonia

★ Uric acid is water soluble and less toxic than ammonia or urea. Uric acid is in the form of crystals.

Urea, uric acid, and ammonia are all ways to eliminate excess quantities of nitrogen.

In many types of invertebrates such as annelids, and mollusks we see nephridium which function similar to the vertebrate kidney.

A contractile vacuole is a structure or organelle used for osmoregulation and waste removal.

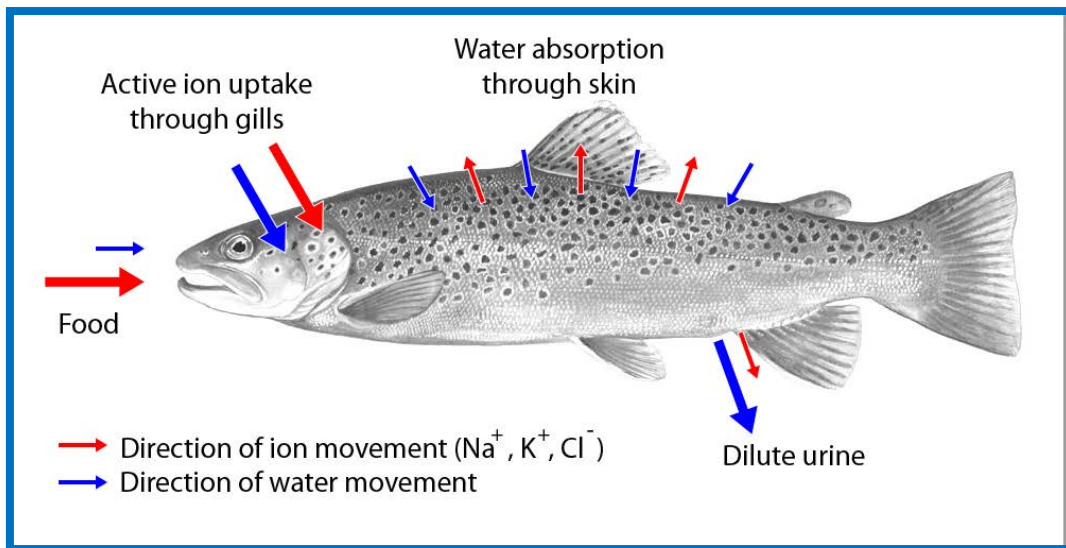
Contractile vacuoles are found in such organisms like: paramecium, amoeba, some algae, some fungi, and hydra.

Flame cells function as excretory cells in flatworms (Platyhelminthes), and rotifers (microscopic, multicelled, aquatic animals. They can be found in lakes, rivers, or streams. They also can be found on moss and lichens growing on rocks). Yes, rotifers are microscopic animals!!!

Flame cells essentially function like a kidney, aiding in waste removal.

Fish

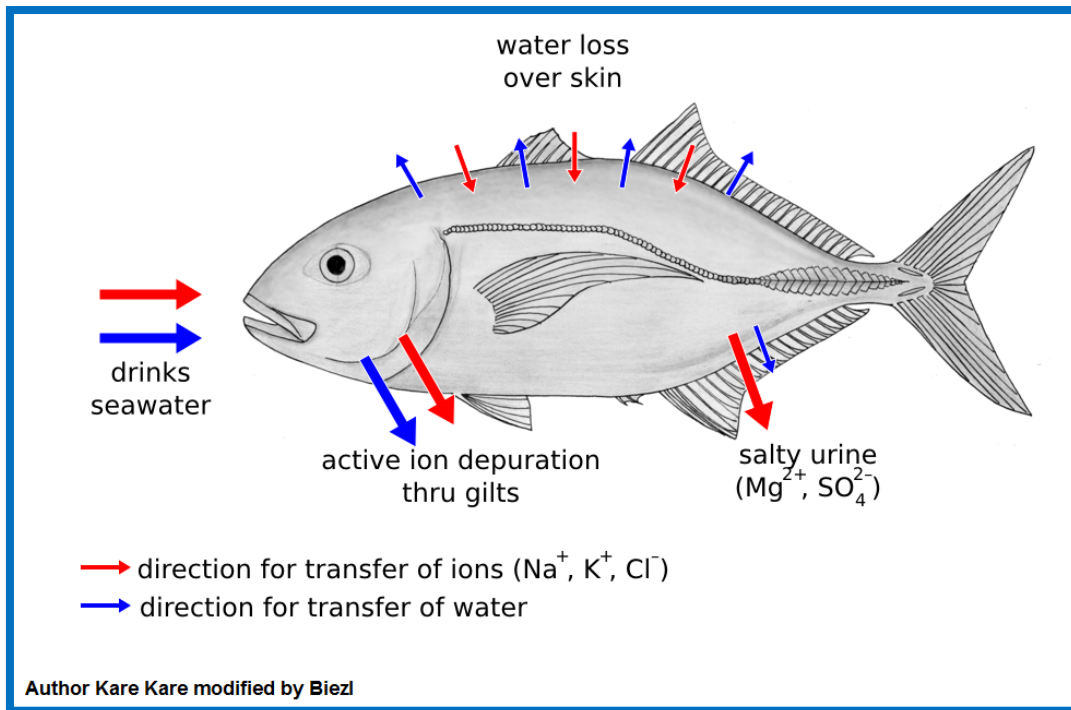
Freshwater Fish:



- a) Large amounts of urine are made
- b) Urine is less concentrated than fluids of the body, dilute urine

Chapter 31- The Excretory System

Bony Marine Fish:



- a) Small amount of urine
- b) Urine fairly concentrated, but slightly less concentrated than body fluids

A favorite DAT problem-type!!!

Why do women tend to get urinary tract infections more than men?

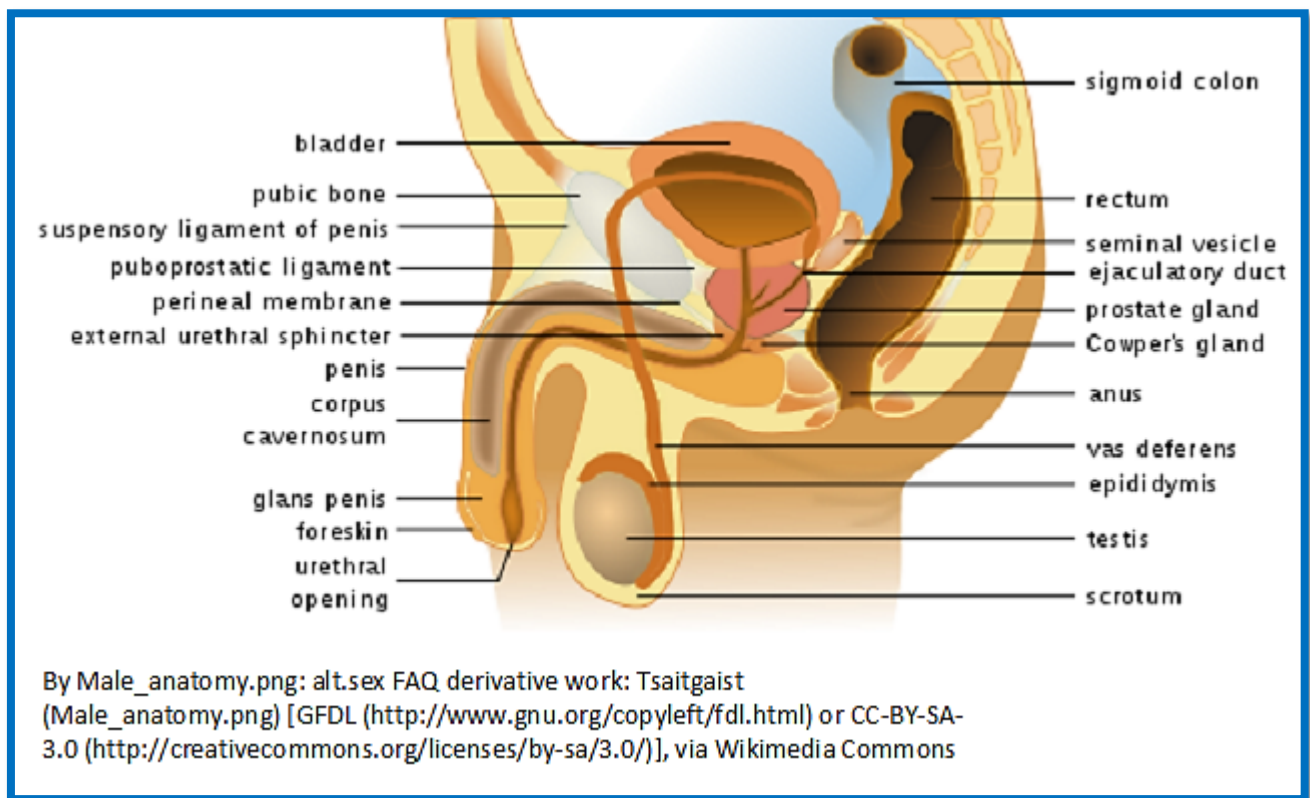
Bacteria can reach the bladder of a woman far more easily than that of a man. The urethra is shorter in the female than in the male. This means that the bacteria have a much shorter path distance to travel. Bacteria have an easier access path!!

Symptoms of a urinary tract infection include: painful urination, burning sensation when urinating, feeling the urge to urinate but cannot, malaise, cloudy, dark urine which smells bad and might even contain blood.

Recall, blood cells were reabsorbed and should never be in urine under normal circumstances. Blood in the urine is called hematuria. Sometimes hematuria is not visible to the naked eye, and can only be detected by a lab.

Chapter 32- Male Reproductive System

The Male Reproductive System

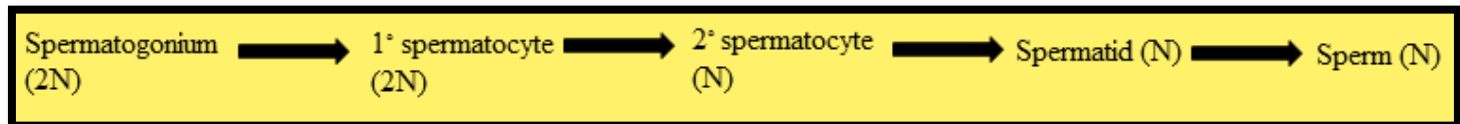


The male reproduction system is comprised of:

a) penis b) testes c) genital ducts e) accessory glands Female Reproductive System

Function: hormone production and sperm production.

Recall spermatogenesis: gave rise to four sperm cells



Temperature is important in the regulation of spermatogenesis, it occurs only below 37°C. Actually, 34°C is maintained in the **scrotal sac**.

Spermatozoa and genital duct secretions make up the semen, which is introduced into the female reproductive tract through the **penis**.

The male gonads are the **testes** that are suspended in a saclike structure called the **scrotum**.

The testes consist of tubules called **seminiferous tubules**. Spermatozoa form here. These tubules are surrounded by loose connective tissue rich in blood vessels, lymphatics, nerves, and **Leydig cells**. Leydig cells produce **testosterone**.

Chapter 32- Male Reproductive System

About 1000 seminiferous tubules are found in the two testes.

2 types of cells in the seminiferous epithelium:

a) **Spermatogenic cells**

b) **Sertoli cells:** these are the “nurse” cells. They protect, support, and give nourishment to the spermatogenic cells. Sertoli cells also do a bit of phagocytosis of cytoplasm eliminated during the production of sperm.

★ Testosterone synthesis occurs at puberty in the male, when the hypothalamus begins the production of gonadotropin-releasing hormone (GnRH).

GnRH tells the anterior pituitary gland to release LH and FSH.

LH causes the Leydig cells to secrete testosterone.

FSH binds to the Sertoli cells and aids in spermatogenesis.

Elevated levels of testosterone inhibit the secretion of GnRH. This is a negative feedback mechanism.

High sperm count also induces the Sertoli cells to secrete inhibin which inhibits production of FSH.

A: Urinary bladder- stores urine

B: Testis- sperm production

C: Epididymis- maturation of sperm. It is here that sperm attain maturation, motility, and membrane receptors for the zona pellucida protein, also acrosomal maturation

D: Scrotum- maintains testes, saclike structure

E: Penis- conveys urine through urethra to outside body, becomes erect and involved with copulation

F: Prostate gland- secretes and stores a significant contribution to the seminal fluid that is released upon ejaculation

The prostate gland secretes a white, slightly alkaline fluid that makes up a portion of the semen. Semen is made alkaline to help neutralize acidity of the vaginal tract.

The prostate contains smooth muscle that helps expel semen during ejaculation.

This gland is a common site for cancer in men over age 65. A product of the prostate called prostate-specific antigen (PSA) is secreted in the blood. During malignancy, the PSA concentration usually increases. This is a useful diagnosis used by doctors to test for prostate cancer. Such cancer is often stimulated to grow more rapidly by testosterone, and inhibited by estrogen. One possible treatment is to remove the testes, which is the main source of testosterone and administer estrogen.

G: Vas Deferens- a tube that conveys the sperm to the ejaculatory duct

★ The ejaculatory duct empties into the urethra.

Chapter 32- Male Reproductive System

Now... producing sperm for reproduction does not only include secretions from the prostate. Other **accessory glands** include:

- a) Bulbourethral or Cowper's glands
- b) Seminal Vesicle

Seminal Vesicles (paired structures):

Make up 60% of semen volume

Contains amino acids, proteins, prostaglandins, Vitamin C, but fructose is the main constituent (**favorite exam type question!**)

Why fructose? It provides the fuel needed for the very motile sperm!

Bulbourethral Gland:

Secretes a thick mucus that aids in neutralizing any acidic urine in the urethra, and aids in lubricating urethral lining.

Fluid from these glands are released in response to sexual stimulation, and can carry some sperm cells. Thus, it is theoretically possible to have a pregnancy from this fluid alone, even without ejaculation.

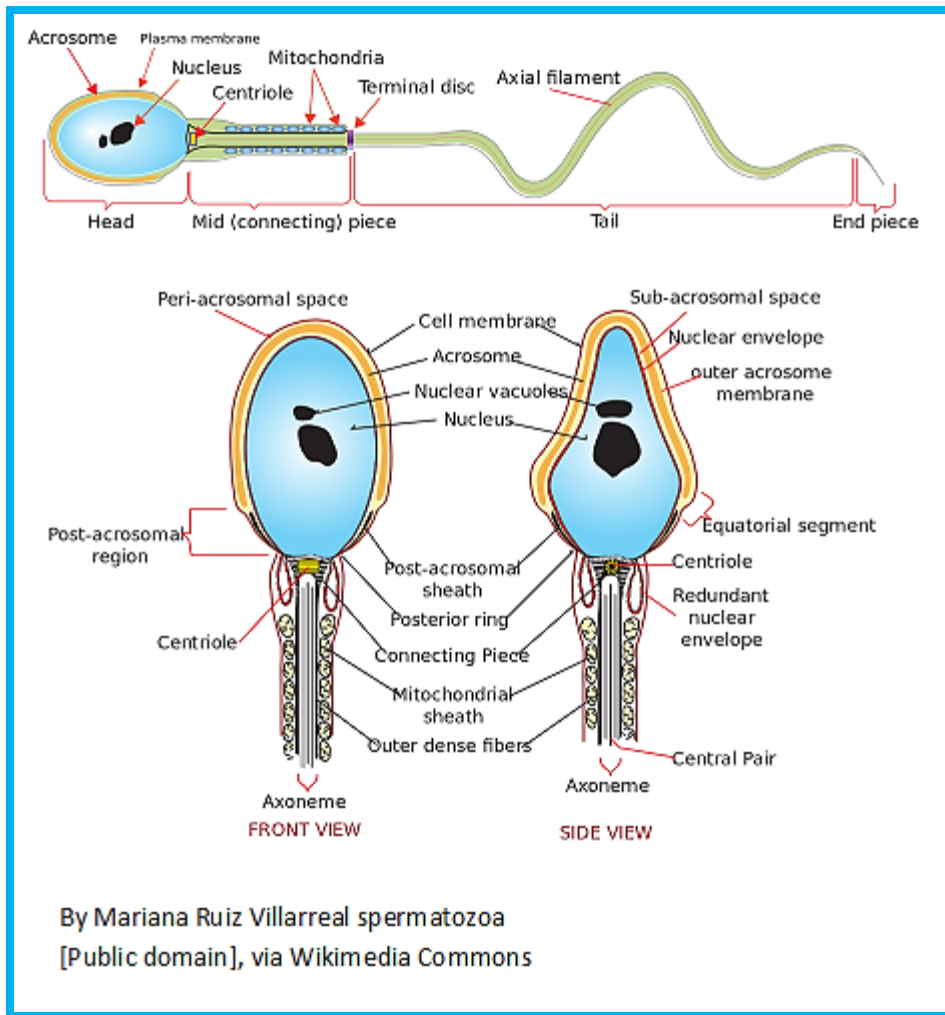
Sperm cells remain immobile when in the testes and epididymis, but become activated when the accessory gland secretions are mixed!

This semen (seminal fluid) that is conveyed to the outside has a pH of about 7.5!

Remember: It now contains many nutrients that will function in helping to enhance the survival of the sperm through the female reproductive tract. One ejaculation of 5 mL may contain over 100 million sperm, to put this in perspective for you.

Chapter 32- Male Reproductive System

Let us examine a mature sperm cell:



Head:

Contains the nucleus, and has a small part at the anterior end called the **acrosome**. The acrosome contains the digestive enzymes (hyaluronidase and arcrosin) that will be involved with breaking down the zona pellucida. This will allow the haploid sperm to join with the haploid egg (secondary oocyte) in syngamy (also called fertilization). A zygote is totipotent!!

Upon contact with the jelly coat of the egg, we trigger exocytosis from the acrosome. The acrosomal enzymes literally drill a hole into the egg. The acrosome is actually an organelle derived from the Golgi apparatus!!

The process of fertilization involves many processes such as:

- 1) **Acrosomal Reaction:** hydrolytic enzyme release
- 2) **Cortical Reaction:** hardening of jelly coat to prevent potential polyspermy
- 3) **Capacitation:** Biochemical changes which allow for sperm to swim better

Neck:

Chapter 32- Male Reproductive System

Contains the sperm centrioles and connects the head to the midpiece

Midpiece:

Contains many mitochondria that provide energy for the sperm movement

Tail:

Actually, a flagellum with a 9 + 2 microtubule arrangement. ATP provided by midpiece mitochondria is essential to allow this movement.

Flagellum movement is a result of the interactions among:

- a) ATP
- b) Microtubules
- c) Dynein: a motor protein with ATPase activity

★ Inside cilia and flagella is a microtubule, 9 + 2, with a cytoskeleton called the axoneme.

Lack of dynein can result in infertility and is characterized by immotile spermatozoa.

Dynein is actually a family of motor proteins involved with transport and providing forces during mitosis.

Interestingly, the egg secretes progesterone which gives the sperm a “boost” of energy, which allows them to swim better as they journey towards the egg. Much research is going on to study this.

I have done much studying on this fascinating event. Recently, it was found that progesterone activates a calcium channel called CATSPER.

CATSPER is vital for male fertility. These channels seem to be specific for sperm. Activation of these channels is now under great research- stay tuned!

Do any animals have internal testes? Yes!

Whales and dolphins are examples of animals that have internal testes. They have body temperatures sufficiently low enough to allow sperm maturation.

In mammals, the entire sperm cell including the flagella and mitochondria enters the egg at fertilization. I have read PhD papers on this and believe it or not, there is no general consensus as to why the loss of paternal (dad's) DNA occurs!!

Thus, I will just say that you need to know that the mitochondria you have is from your mom!!

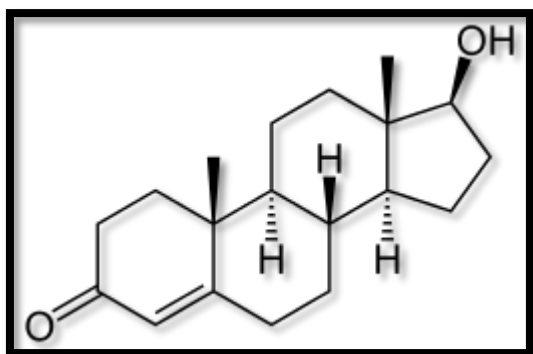
I found this great essay for you to read if you want:

Misconceptions about mitochondria and mammalian fertilization: Implications for theories on human evolution

Friderun Ankel-Simons and Jim M. Cummins[†]

Chapter 32- Male Reproductive System

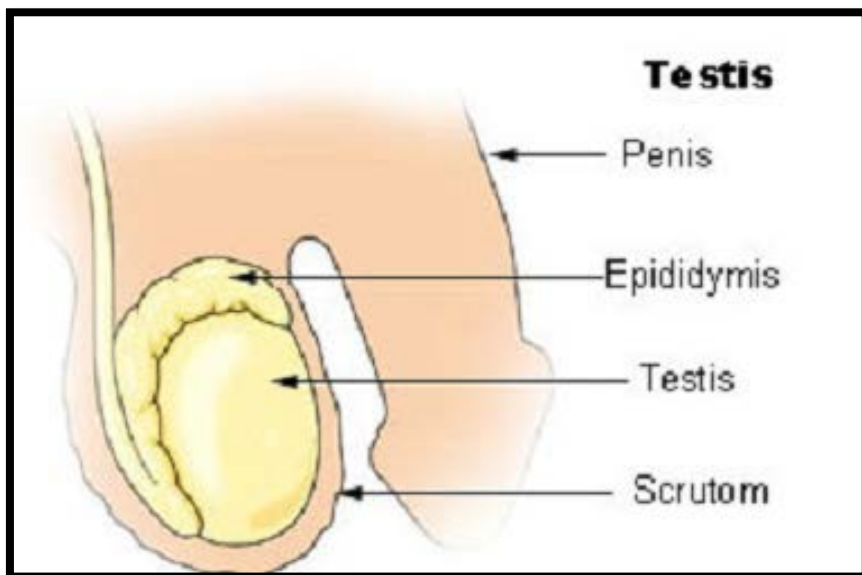
Let us re-visit the Leydig cells again. These cells made testosterone.



Leydig cells are typical steroid-producing cells consisting of large accumulation of smooth endoplasmic reticulum, and a well-developed Golgi apparatus.

Testosterone will be involved in muscle growth, as well as for the development of male secondary sex characteristics such as growth of the male genitalia, increased body hair, thickening of the skin, strengthening of muscles and bones, thickening of the vocal chords, and sometimes even a decreased growth of hair on the scalp.

After age 25, a gradual decline in testosterone levels occur.



Those with Klinefelter's syndrome, XXY, have very low levels of testosterone which results in the underdevelopment of the usual male secondary sex characteristics. In a Klinefelter male, men are unable to produce sperm due to low testosterone levels, as a result, the male is infertile. Remember, the precursor molecule for testosterone is cholesterol.

Leydig cells actually release a class of hormones called androgens. They include:

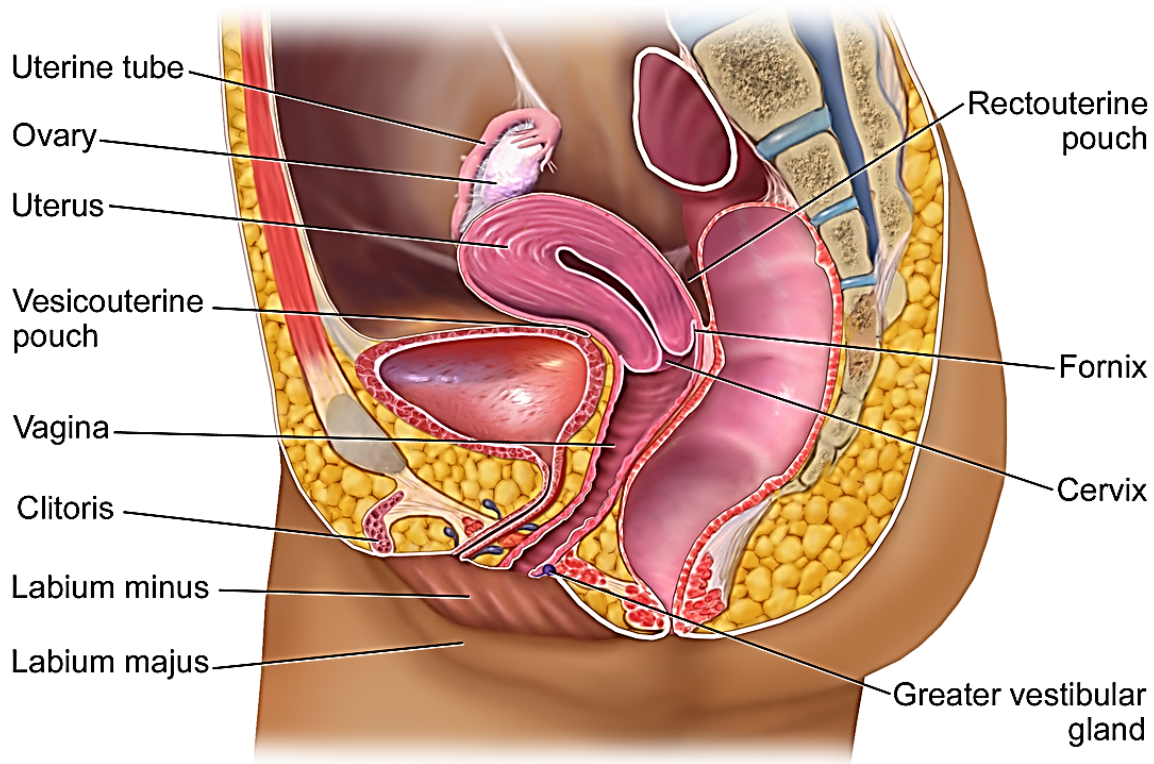
Chapter 32- Male Reproductive System

- 1) Testosterone
- 2) Androstenedione
- 3) Dehydroepiandrosterone (DHEA): early pubic hair growth, increased oiliness of the skin and even acne!

For your purposes, testosterone is the main hormone of focus.

Chapter 33- Female Reproductive System

Female Reproductive System

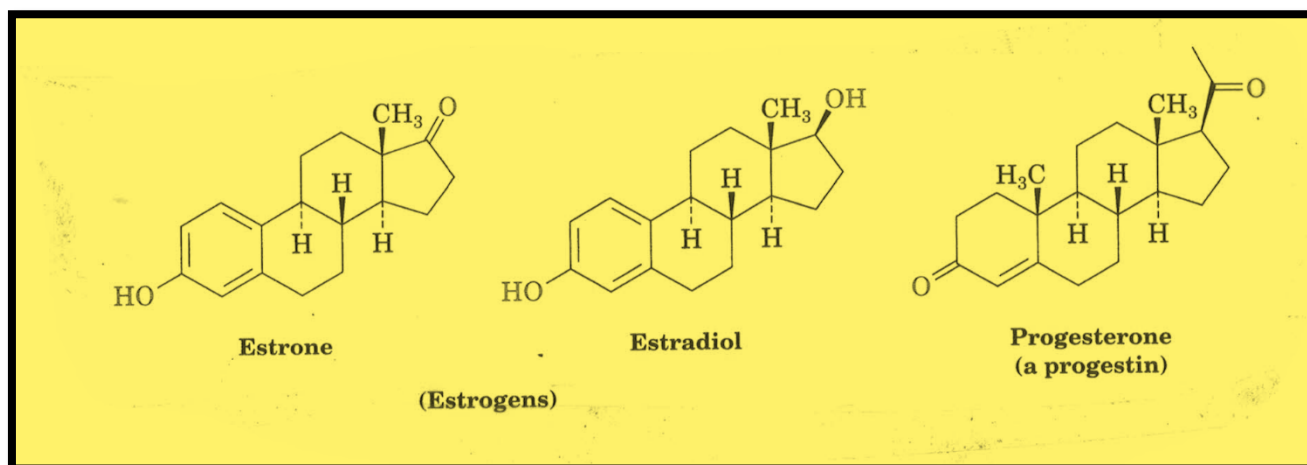


The Female Reproductive System

The ovary is the primary reproductive organ in the female. They are paired, and held in place in the lower abdominal cavity by ligaments. Like the testes, they have a dual function:

1. Making and releasing eggs
2. Secretion of estrogen and progesterones

Chapter 33- Female Reproductive System

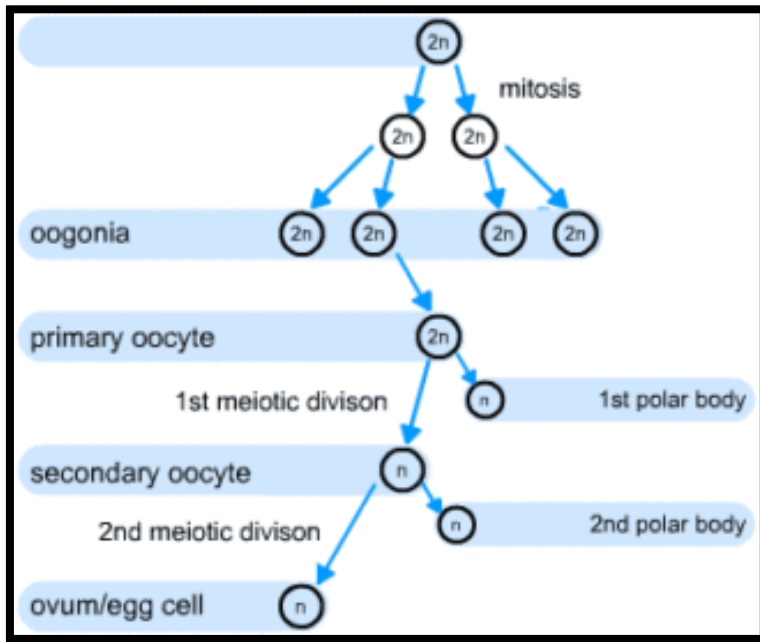


Female body form and other secondary sex-characteristics develop due to these hormones.

Chapter 33- Female Reproductive System

Oogenesis

Recall, **the formation of an egg is called oogenesis!**



For the DAT, make sure you know:

Primary oocyte = $2N$

Secondary oocyte = N

..etc. **This is a common exam question!!**

The **polar body** is a small haploid cell. This polar body generally does not have the ability to be fertilized. The small polar body has very little of the cytoplasm. The egg (ovum) gets the majority of the cytoplasm. The polar bodies will usually disintegrate by apoptosis. However, there are many unanswered questions regarding polar body biology.

At birth, a female may have 500,000 primary oocytes in each ovary. By puberty, it may decline to 250,000. These cells have not completed their meiotic divisions are in the dormant or resting state.

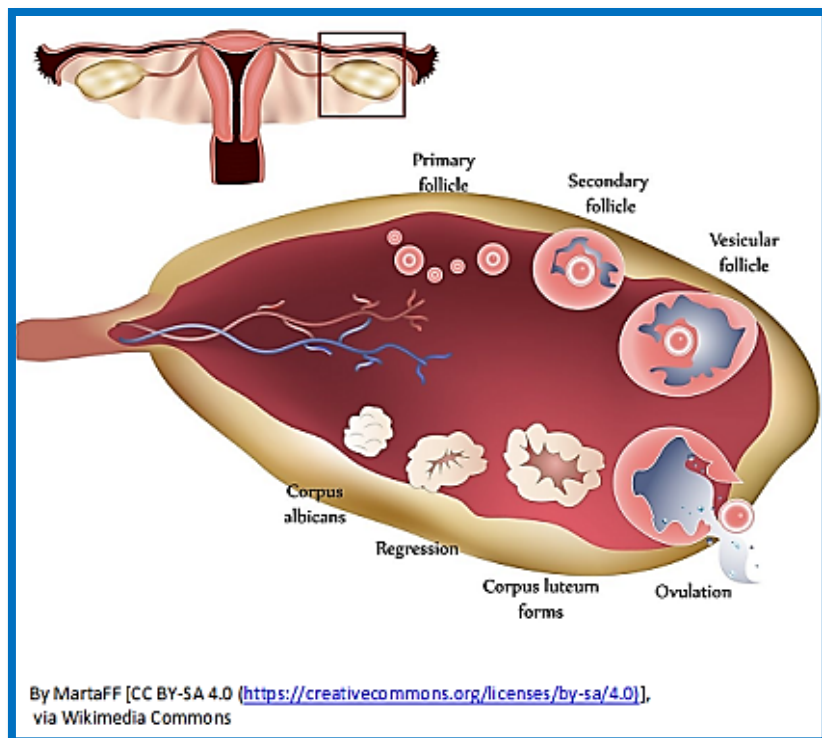
The cells stop dividing at **prophase I of meiosis**.

Contained in the ovary is a special area known as the **follicle**. These primary oocytes arrest development before birth.

At puberty, FSH stimulates a small group of these follicles to begin growth and development.

Each month, one follicle fully matures. At ovulation, the follicle breaks open and releases a secondary oocyte.

Chapter 33- Female Reproductive System



Ovulation, as you can see by this picture, involves a small rupture of the ovarian wall.

This accounts for the slight pain women feel at the time of ovulation.

This occurs every 28 to 30 days.

Many ovarian follicles undergo atresia, in which follicle cells and oocytes die. They are removed by phagocytic cells.

This **secondary oocyte** is what gets fertilized by a sperm cell.

What happens to the ruptured follicle within the ovary?

It develops into the **corpus luteum**. The corpus luteum is a temporary endocrine gland that makes progesterone, and some estrogens and androgens. This progesterone and estrogen combo inhibits the secretion of LH and FSH. What does this mean?

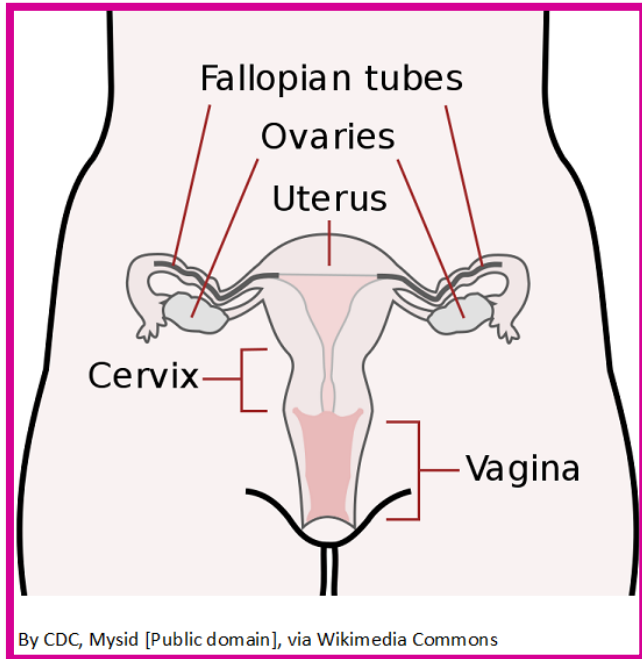
1. Without FSH: there is no new follicle development, thus no second ovulation
2. If no pregnancy, the absence of LH leads to the degeneration of the corpus luteum into what is called the **corpus albicans**. This is simply fibrous tissue that is eventually reabsorbed. The remnants simply persist as scar tissue on the ovarian surface. Corpus albicans means “white body” due to the large amount of collagen.

Hopefully you can see that FSH and LH regulates the maturation of the follicles as well as ovulation.

Chapter 33- Female Reproductive System

If pregnancy does occur, the corpus luteum does not degenerate and continues to make estrogens and progesterone which will help maintain the uterine lining (endometrium).

Let us see a picture before we see the fate of our secondary oocyte:



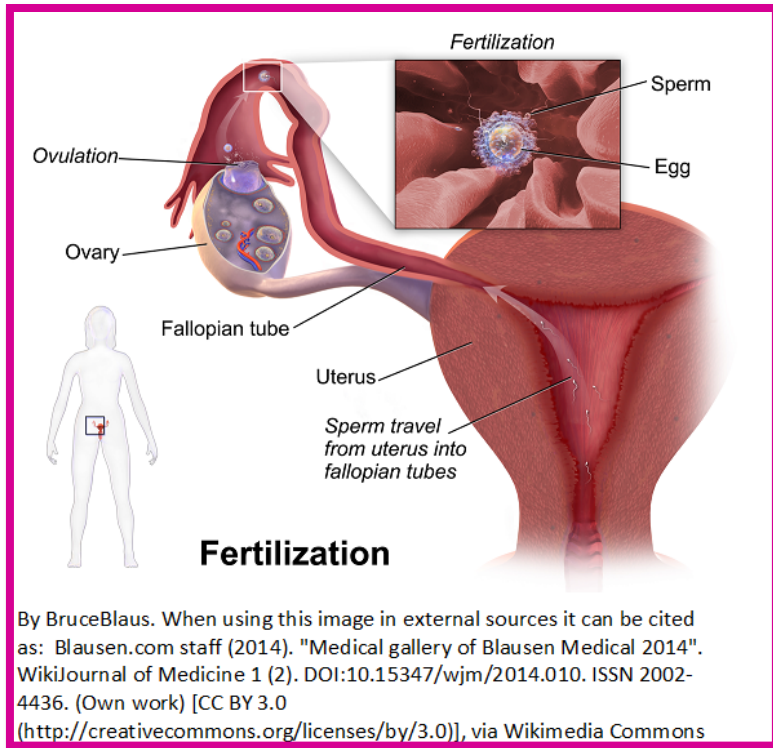
Blocked oviducts are one of the most common causes of infertility. The outer end of each tube is funnel shaped and contain the fimbria. The fimbria catch the secondary oocyte and channel it down into the fallopian tube when released by the ovary. The fallopian tube has two different cell types:

- A) Non-ciliated peg cells
- B) Ciliated cells

Peg cells provide a nutritive and a protective environment for maintaining spermatozoa as they move towards the secondary oocyte. Peg cell secretions are believed to be involved with the process called **capacitation**. This is a process by which the spermatozoa become fully mature and capable of fertilizing the egg.

The ciliated cells beat in unison and allow the fertilized ovum to be propelled toward the uterus.

Chapter 33- Female Reproductive System



The uterus is the womb!

This is a muscular organ who receives the fertilized egg and sustains its life during development.

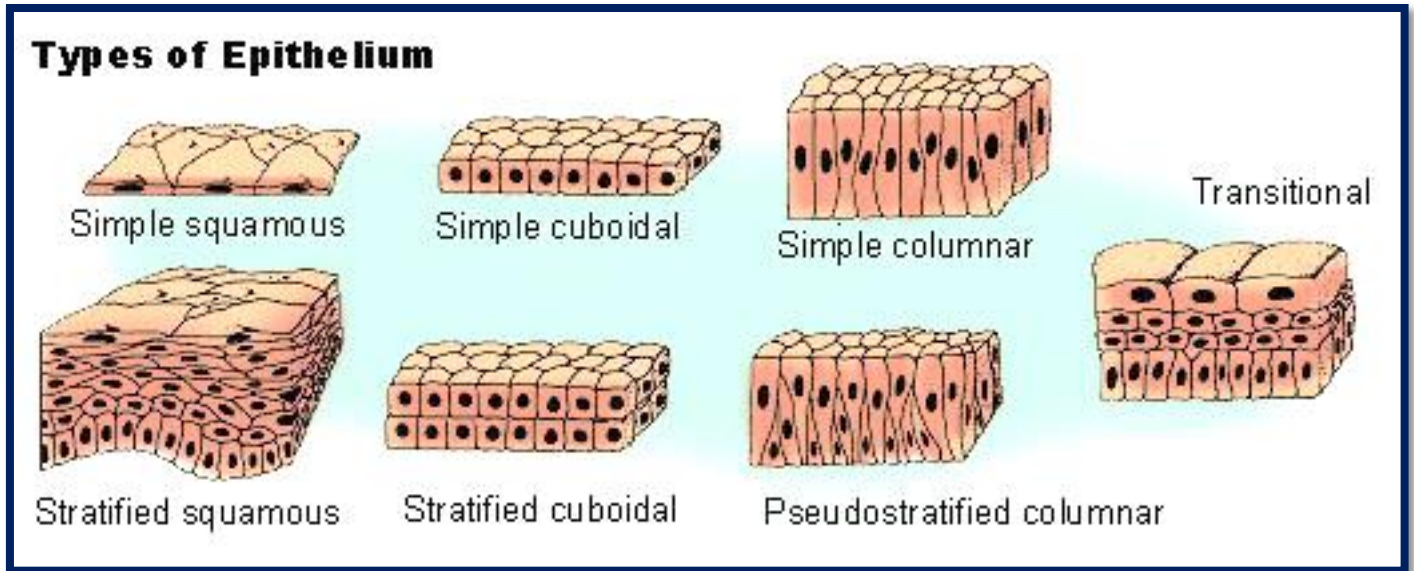
The lower third of the uterus is called the **cervix** or neck of the uterus. The cervix opens into the **vagina**.

The inner lining of the uterus is highly vascularized, in other words, rich in blood vessels. This lining is the endometrium.

The endometrium contains a mixture of ciliated and secretory simple columnar cells.

The following picture is a quick review of cell types:

Chapter 33- Female Reproductive System



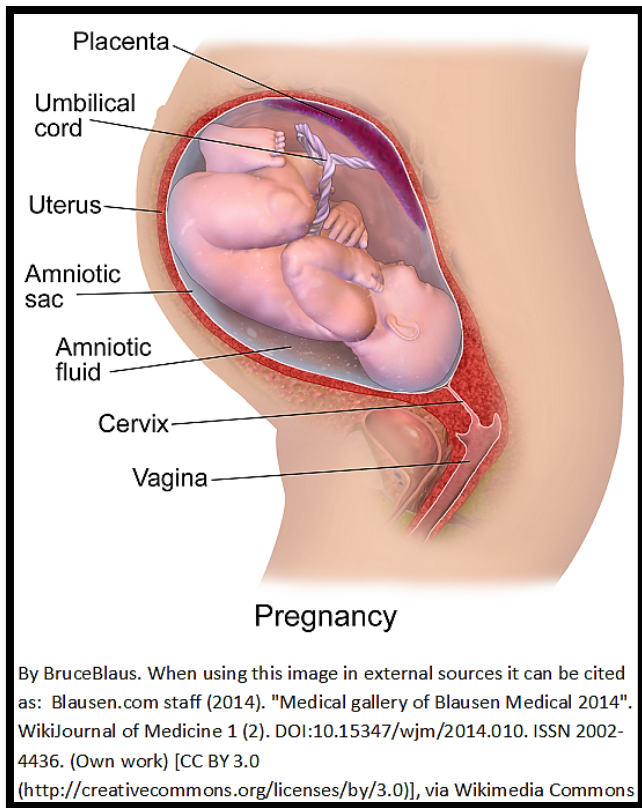
The vagina is an extended, thin-walled tubular canal that connects the cervical area with the outside of the body. Parts of the vagina include: the labia majora, labia minora, and the clitoris which contains erectile tissue similar to the male penis. The clitoris is highly sensitive and richly supplied with nerve endings.

It takes 24 hours for the zygote to begin dividing, this is called cleavage! It is about 2-3 days before implantation in the uterus occurs.

By the time the zygote gets to the uterus, we see about 16 cells. At the one-week mark, we call it a **blastocyst**. It floats in the uterus for several days, before finally implanting in the endometrial lining. Thus, implantation of the blastocyst into the endometrium is now done, 7 days in all!!

Chapter 33- Female Reproductive System

It will take 9 months for a baby to be made. **3 trimesters are noted:**



1st trimester:

Mostly radical changes occur

Body structures start to differentiate

Outer layer of blastocyst grows outward and is called a trophoblast which eventually forms the placenta.

Organogenesis occurs here- it is here that the embryo is most sensitive to radiation, toxins, and drugs.

At 8 weeks, the embryo is called a **fetus**.

2nd trimester:

Rapid fetal growth continues

Mother can feel fetal movements

Hair develops on the head

Waxy secretions cover the skin to protect it from the watery amniotic fluid.

Fetus now shows reflexes as sense organs become functional.

Chapter 33- Female Reproductive System

Babies born at the end of this trimester, (i.e. 6 months) could possibly survive but would need intensive medical care under strictly controlled conditions.

3rd trimester:

More growth as mother's uterus continues to expand and move higher in the abdominal cavity.

Brain developments and PNS development accelerates.

Testes descend in the male out of the abdominal cavity. If they do not descend, we see the condition known as cryptorchidism. This will cause a too warm environment to produce normal sperm. If you recall, the sperm needed a slightly lower temperature for proper functioning.

Maternal antibodies cross the placental barrier and enter the fetal circulation. This allows the newborn infant (neonate) to carry immunity against invaders like viruses, fungi, and bacteria.

This is called passive immunity. Eventually, the infant's own immune system begins to make antibodies for its own defense shortly after birth.

After an extended period of labor (rhythmic uterine contractions) birth occurs. This is called parturition.

The hypothalamus signals the anterior pituitary gland to secrete prolactin which stimulates the mammary glands to produce milk.

Suckling also stimulates oxytocin, which triggers milk release.

Bottom Line:

- a) Prolactin: stimulates milk production
- b) Oxytocin: milk ejection, also stimulates uterine smooth muscle contraction

Fetal Circulation

During the fetal stage, the maternal blood supplies the needed O₂, nutrients and will carry away the waste products. The placental membrane will allow these substances to diffuse.

The fetal vascular system needs to make a few adaptations.

Five structures you need to know:

Umbilical Artery: low in O₂ will carry blood to the placenta

Umbilical Vein: high in O₂, will carry oxygenated blood from the placenta to the fetus

Foramen Ovale: allows blood to bypass the lungs. Blood is shunted from the right atria to the left atria. The foramen ovale will normally close after birth when the lungs become functional. (Don't forget- the lungs of the fetus are not functional, thus this allows a by-pass).

Ductus Venosus: allows blood to bypass the liver, partially. About 50% of the blood pass into the liver, the rest is shunted away by the ductus venosus to the inferior vena cava.

Chapter 33- Female Reproductive System

Ductus Arteriosus: the lung bypass. Conducts most of the blood from the pulmonary artery to the aorta. This allows the lungs to be bypassed.

If the egg does not get fertilized, there will be a shedding of the endometrial lining. Blood, along with this lining defines menstruation. This flow will be in a direction outside of the vagina.

Two cycles are involved:

- 1) Menstrual Cycle (averages 28 days)
- 2) Ovarian Cycle

Ovarian Cycle

We will call the start of this process Day 1:

During the early days of the ovarian cycle, GnRH stimulates the anterior pituitary gland to secrete small amounts of FSH and LH.

3. FSH causes the follicle containing the prospective egg to mature and proceed toward ovulation. Several follicles grow, but usually one makes it to the full maturation.
4. As the follicle grows, estrogens, primarily one called estradiol, stimulates the growth of the uterus, and rapidly replaces those layers shed by the previous menstrual cycle. This lasts about 10 days after the end of menstruation. At the cycle midpoint the anterior pituitary gland releases a surge of LH hormone. We call this the luteal surge. This increase in LH in response to an increase in estradiol is a fine example of a positive feedback mechanism.
5. We now see the follicle maturing. 24 hours after this surge of LH, all hell breaks loose, the ovarian wall ruptures and the secondary oocyte is released. This is often felt as a slight pain in the abdomen of the female when this event occurs. Depending on which ovary is involved, the pain can be on the left or the right side.
6. The luteal phase now follows ovulation in this ovarian cycle.

Under the direction of LH, a “yellow body” called the corpus luteum forms from the follicle. This corpus luteum makes: progesterone and estradiol.

As the two hormones rise in level, a negative feedback occurs. We decrease FSH and LH to very low levels. Soon after, the corpus luteum disintegrates since there is no pregnancy. As we disintegrate the corpus luteum, progesterone and estradiol levels sharply decline. The cycle can begin again when the pituitary gland secretes enough FSH to allow a new follicle to grow and we initiate the next ovarian cycle. **Do not confuse this up- we have just seen the ovarian cycle!**

Menstrual (Uterine) Cycle

We divide it into the following phases:

- 1) Menstrual Phase (Day 1-4)
- 2) Proliferative (Follicular) Phase (Days 4-14)
- 3) Secretory (Luteal) Phase (Days 15-28)

Chapter 33- Female Reproductive System

For the DAT both names of proliferative and secretory need to be learned!

Let's go through each:

Menstrual Phase:

With no fertilization, bleeding starts

Upon low levels of progesterone and estradiol, because the corpus luteum has disintegrated, we see arteries in the endometrium constrict. O₂ levels are now reduced and this leads to glandular shutdown, invasion by leukocytes, and the uterine lining breaks down and begins disintegration. Blood tissue (endometrial) are now shed. This continues for about 4 days. (35 mL is the average blood loss, although in some women, it can be more).

Proliferative (Follicular) Phase:

Days 4 to 14

Occurs at the same time as the development of the ovarian follicles

We begin this phase as menstruation ends.

We see enlargement of arteries and uterine glands, along with reconstruction of connective tissue, new epithelization occurs

Functional layer becomes thicker due to proliferation of the cells at the base of the glands that did not get "washed away" during menstruation. Their blood supply was left intact.

As Day 14 is approached (i.e. the Big Day is here!!), the endometrium has been fully restored to its previous status. I hope you can see that the ovarian and menstrual cycles are coordinated with each other.

Secretory (Luteal) Phase:

Day 15 to 28

Begins after ovulation

Endometrium continues to thicken; arteries attain full development...

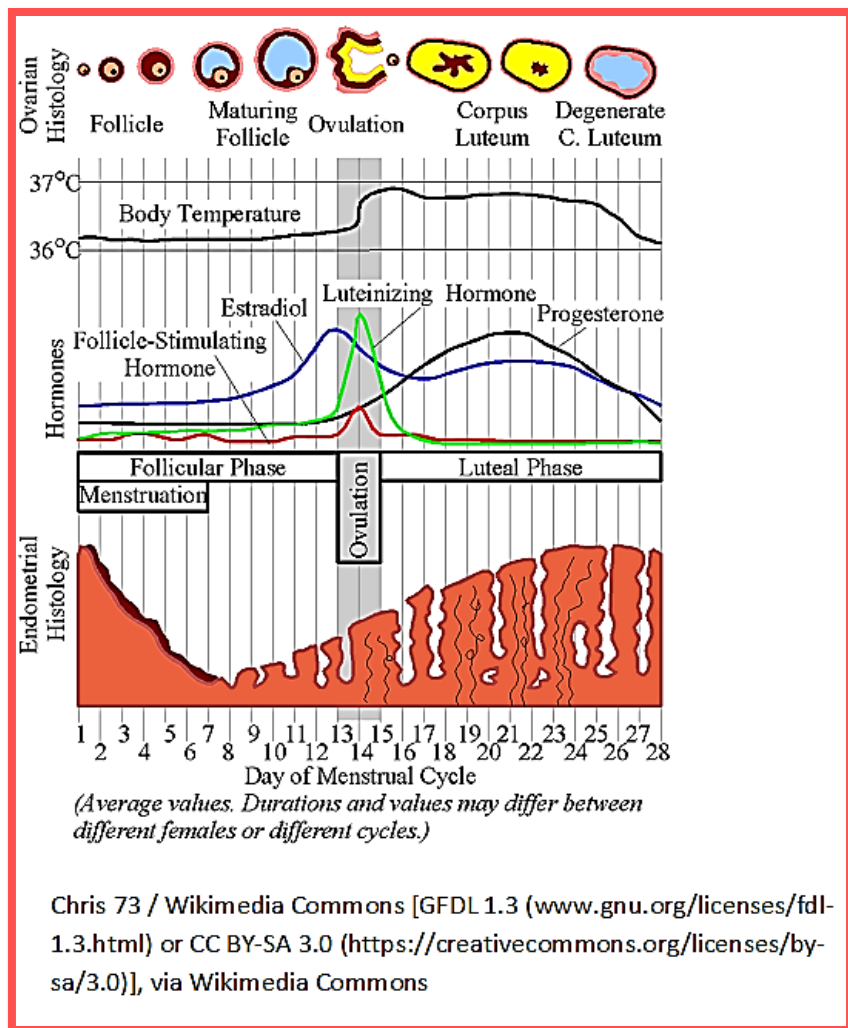
★ Progesterone levels are the highest during this phase, more than any other hormone.

If fertilization has taken place in the day following ovulation, the embryo makes its journey to the uterus several days later. The uterine gland secretion is the major source of embryonic nutrition that is required before and during implantation.

If no pregnancy, our cycle is repeated.

It is possible that viable cells from the endometrium are displaced during menstruation. These cells can move upward to the fallopian tubes, or grow outside the uterus in areas such as the bladder or colon. This afflicts 3% of women under the influence of estrogens and progesterone this ectopic tissue grows and degenerates monthly without effective removal. Pain, inflammation, cysts, and scar tissue can result and lead to infertility. This is called endometriosis.

Chapter 33- Female Reproductive System



Menopause occurs around 48 years old. Ovarian response to LH and FSH decrease, and estrogen levels plunge.

Why does this occur?

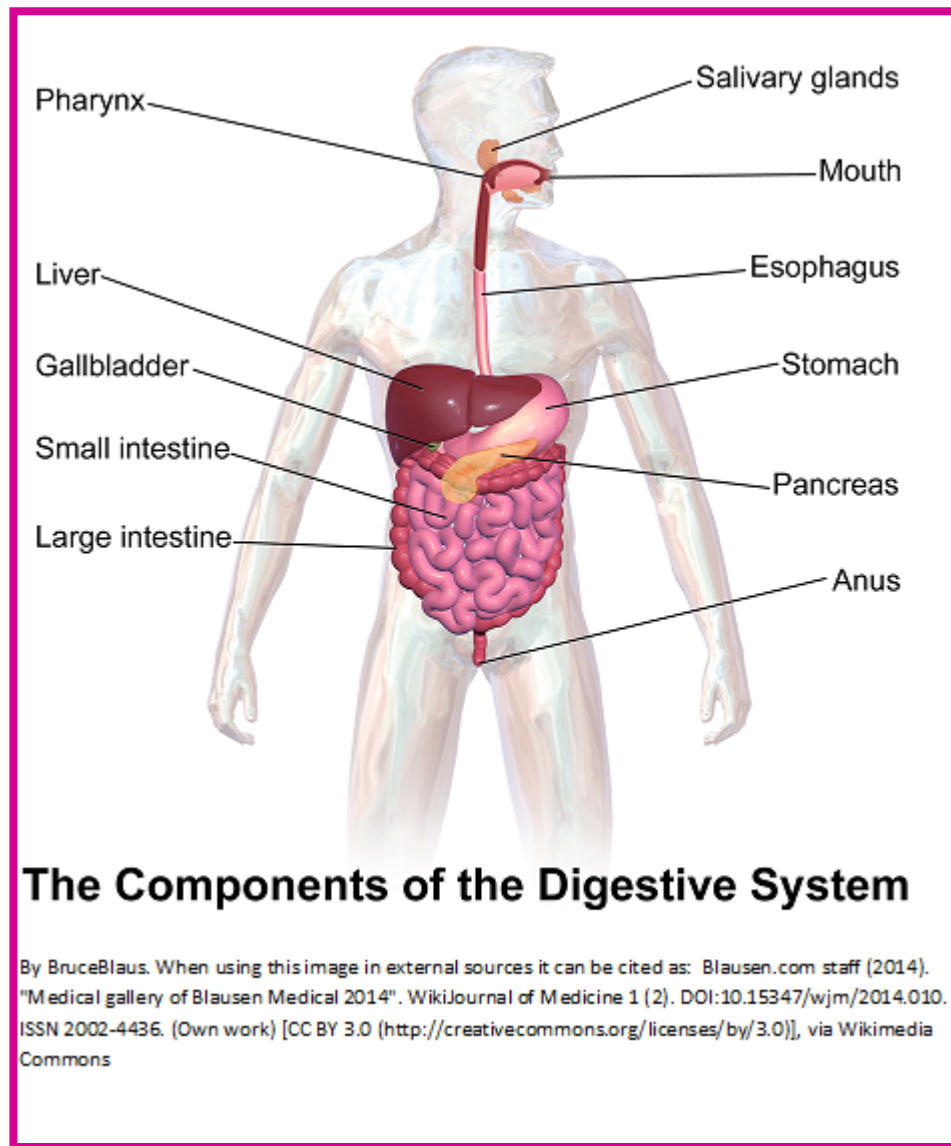
Many theories have been proposed, but one states that during human evolution, the mother is needed to provide care for her offspring. This will allow an increase in survival.

Only humans and a few primates (apes and chimpanzees for example), have a menstrual cycle. Others have an estrous cycle.

Animals that have an estrous cycle reabsorb the endometrium if conception does not occur during the cycle. In species with these cycles, females are generally only sexually active during their estrous cycle. This is sometimes referred to as “animals in heat” For females that have menstrual cycles, this is not true.

Chapter 34- The Digestive System

The Digestive System



The human digestive tract if it was to be fully stretched out in the adult would measure 21 to 30 feet.

Mucus coated epithelium lines every surface facing the lumen. A lumen is simply a space within a tube. The mucus helps protect the wall of the tube and allows diffusion across the boundary.

The digestive tract must fulfill several functions that include:

- 1) Getting the food
- 2) Storing the food
- 3) Transporting the food
- 4) Breaking down the food
- 5) Absorbing nutrients from the food

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6) Evacuation of wastes

Let us begin in the mouth.

Mouth

Food enters through the mouth. Humans are **heterodonts**, in that they have specialized teeth for different actions. Heterodonts have more than a single tooth morphology. A **homodont's** teeth in contrast are all the same. Most reptiles, fish, and amphibians are homodonts.

In adults the permanent teeth number 32. The visible part of the tooth is called the crown. In addition, one or more roots are embedded in a gum socket.

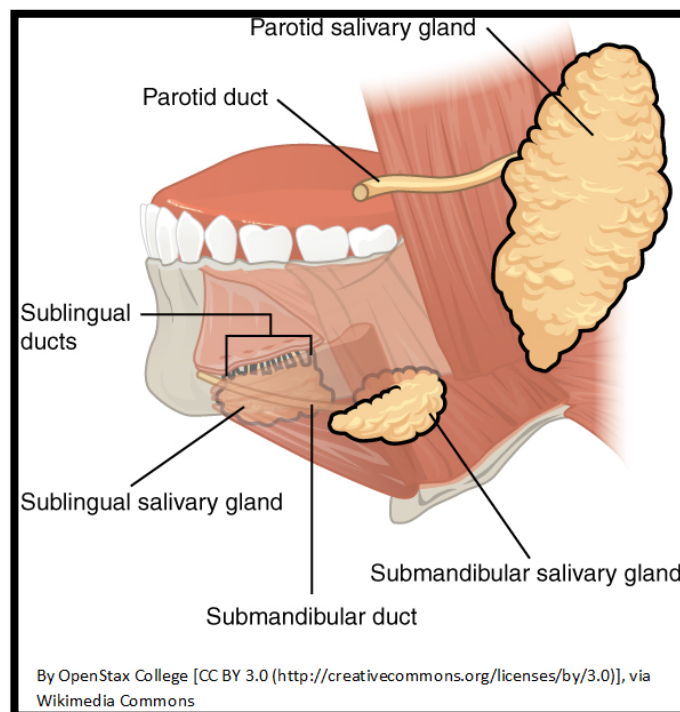
★ The periodontal ligament is a connective tissue rich in collagen that connects the cementum and alveolar bone of the tooth socket.

The tongue has touch and pressure receptors, in addition to taste buds along its surface.

Von Ebner's glands are exocrine glands (they have ducts), in the tongue that secrete **salivary lipase**, beginning the process of **lipid hydrolysis** in the mouth.

The salivary glands include:

- 1) **Parotid:** largest of the glands (mumps, a viral infection is caused due to infection of this gland)
- 2) **Submandibular:** produces 70% of saliva
- 3) **Sublingual:** produces mainly mucous



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Many minor salivary glands are found scattered in areas such as the floor of the mouth, hard and soft palate. Saliva contains an amylase (salivary amylase or ptyalin) that breaks down starch into maltose or glucose depending on the carbohydrate. Salivary amylase, like most enzymes is a protein!

The pH of saliva is usually just over 7, namely about 7.2.

★ I have seen a study that showed that the more alkaline the pH (the more basic the pH), the more patients had generalized chronic gum inflammation (gingivitis), whereas those that had an acidic pH had generalized chronic periodontitis, a condition that involves progressive loss of alveolar bone around the teeth.

The salivary glands help us taste food, initiate the digestive process, and permit us to swallow (deglutition).

Saliva contains the antibacterial agents:

- 1) **I_gA**: a large protein that works with the immune system
- 2) **Lysozyme**: attacks cell wall of many gram positive bacteria (tears also contain lysozyme)
- 3) **Lactoferrin**: part of the innate defense- has antibacterial, antiviral, anti-parasitic properties

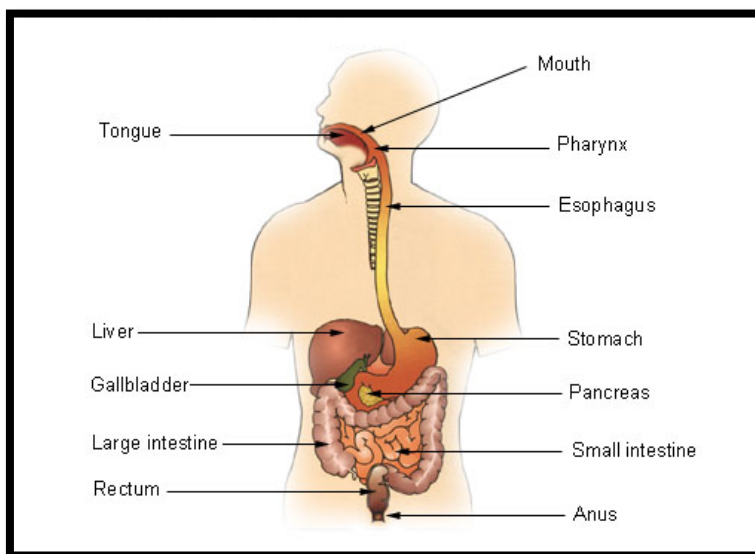
Hopefully, you see that saliva is truly a complex fluid!! No small wonder that animals like dogs and cats lick their wounds!

A glycoprotein called mucin is also present that protects the lining of the mouth from abrasions, and lubricates the food so we can swallow it easy.

Food is shaped into a ball called a **bolus** and pushed to the back of the throat called the **pharynx**. Swallowing is tricky business, because we don't want food to enter the airways. Thus, the **epiglottis** is a flap of cartilage that prevents food from entering the trachea.

★ The epiglottis serves as a valve to prevent food or liquid from entering the trachea. For those that want to see some fantastic diagrams on this, I refer you to the Campbell text.

The bolus now is able to enter the esophagus which connects to the stomach.



Chapter 34- The Digestive System

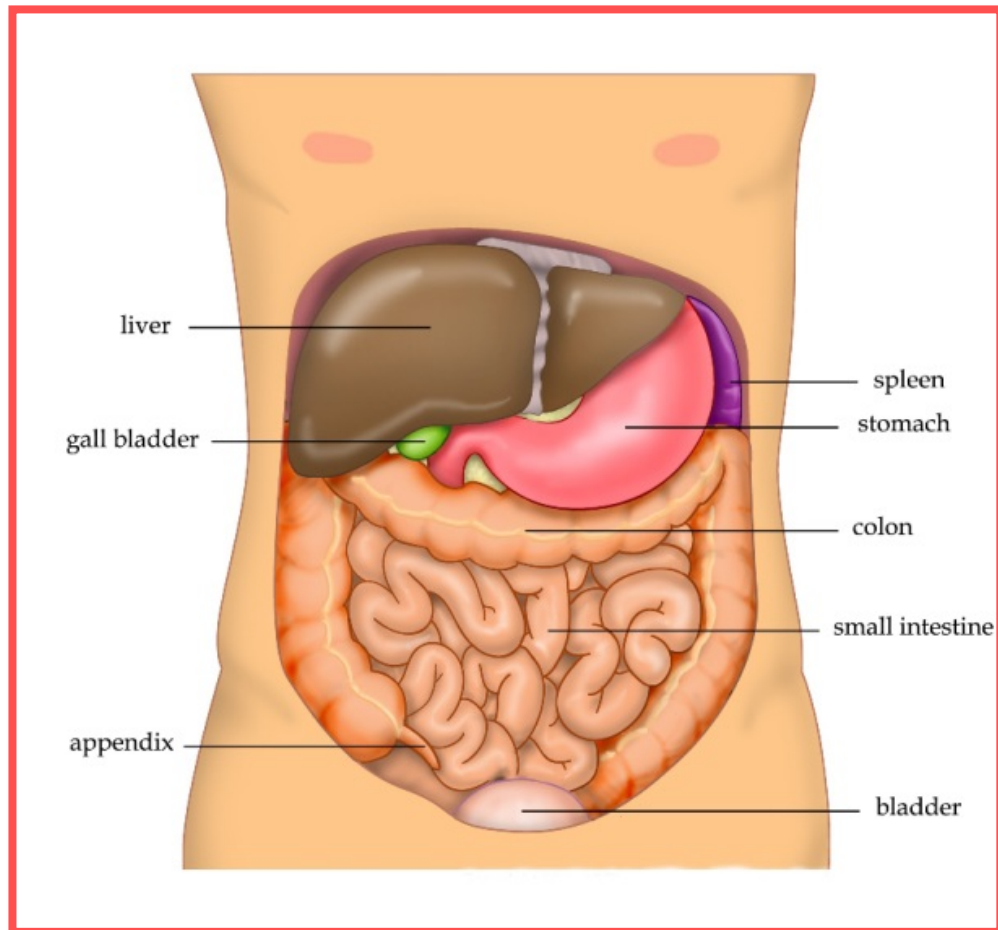
The esophagus is a muscular tube that will transport the food from the mouth to the stomach. Glands in the esophagus secrete mucus which facilitate the transport of foodstuffs. The esophageal mucosa is composed of stratified squamous epithelium.

Recent studies have identified cells called Langerhans cells in the esophageal mucosa. These cells are involved with phagocytosis. Between the esophagus and stomach is the cardiac sphincter. This prevents the backflow of the stomach contents into the esophagus.

Heartburn typically occurs if the stomach contents back up into the esophagus. This occurs when this cardiac sphincter valve does not close tightly enough. Some foods may “relax” the valve too much and it fails to close tight enough.

If you vomit, the valve relaxes itself enough to cause a backwards flow of vomitus. Stomach acid can cause damage to the esophagus and even lead to cancer.

Stomach



Processing and formation of ingested food into a thick acidic fluid called **chyme**.

Chyme is digestive juice and ingested food!

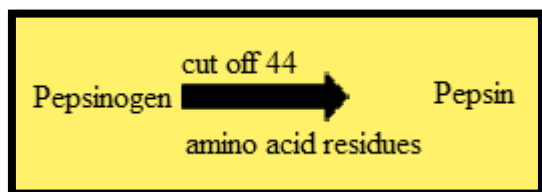
Chapter 34- The Digestive System

pH of the stomach is 1.5. This is a very low pH that will do two main things:

- 1) Destroy pathogens (like bacteria)
- 2) Break down proteins- a protease called **pepsin** is present

The inactive form of pepsin is called **pepsinogen**. It is a proenzyme or zymogen that needs to be activated. Pepsinogen is released by the **chief cells**.

Upon mixing with HCl (made by **parietal cells**):



(once made, pepsin can also convert inactive pepsinogen to more pepsin).

★ **Cleavage** is one of the main ways to “activate” an enzyme. Removal of these 44 amino acids allows for the needed conformational change to “activate” the enzyme. Both HCl and pepsin therefore are involved in this positive feedback.

Gastrin is a peptide hormone that stimulates the secretion of HCl by the stomach parietal cells.

Gastrin is made by G cells of the duodenum of the small intestine as well as cells in the stomach pylorus. The pylorus is simply the furthest part of the stomach that connects to the small intestine (duodenum).

Mucus in the stomach lining protects the stomach from these harsh acidic conditions.

Cells in the stomach lining replace themselves every 3 or 4 days. Chemotherapy drugs are designed to kill cancer cells which are actively dividing. Unfortunately, the drugs also kill these rapidly dividing cells. The cells do grow back but many of the side effects of cancer drugs include diarrhea, and nausea. Stomach and intestinal cells suffer.

Parietal cells:

- 1) Produce HCl
- 2) Gastric Intrinsic Factor: a glycoprotein involved with vitamin B-12 absorption

What is an ulcer?

Damage to the epithelial layer. Substances such as aspirin, and even micro-organisms like Helicobacter Pylori can lead to ulceration.

Believe it or not, lysozyme is also made by glands in the stomach pylorus.

We need not go into any details, but the stomach produces a few little-known hormones.

Enteroendocrine cells are specialized cells of the GI tract.

For example, the stomach makes hormones (although not exclusively) such as:

Chapter 34- The Digestive System

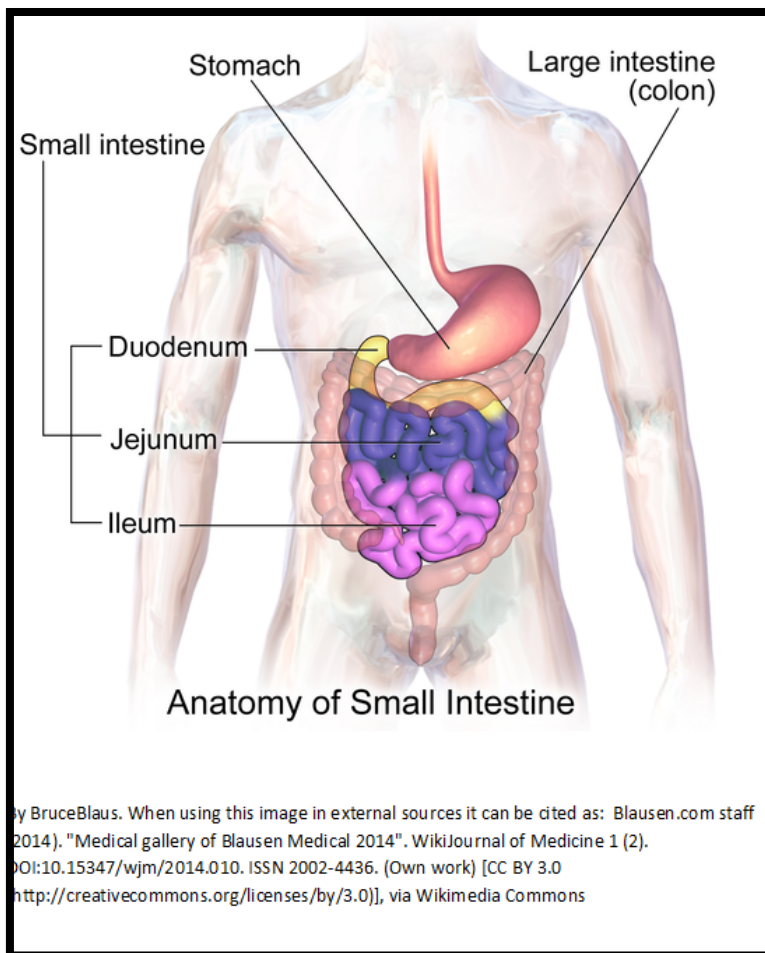
- a) Glucagon (enteroglucagon)
- b) Somatostatin
- c) Serotonin
- d) Substance P
- e) Histamine
- f) Gastrin

Small Intestine

This is where the largest percent of digestion (macromolecule hydrolysis occurs).

Over 20 feet long

There are 3 segments:



- a) **Duodenum:** first segment
- b) **Jejunum:** middle segment
- c) **Ileum:** final segment

Duodenum

Chapter 34- The Digestive System

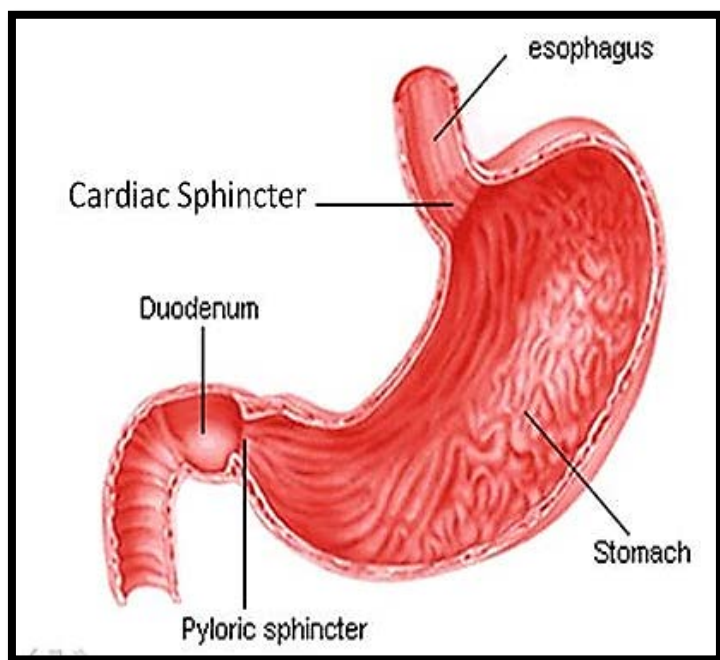
When chyme enters the duodenum, carbohydrates, proteins, and fats are still not totally digested.

Ducts carrying bile and pancreatic juice enter the duodenum about midway along its length.

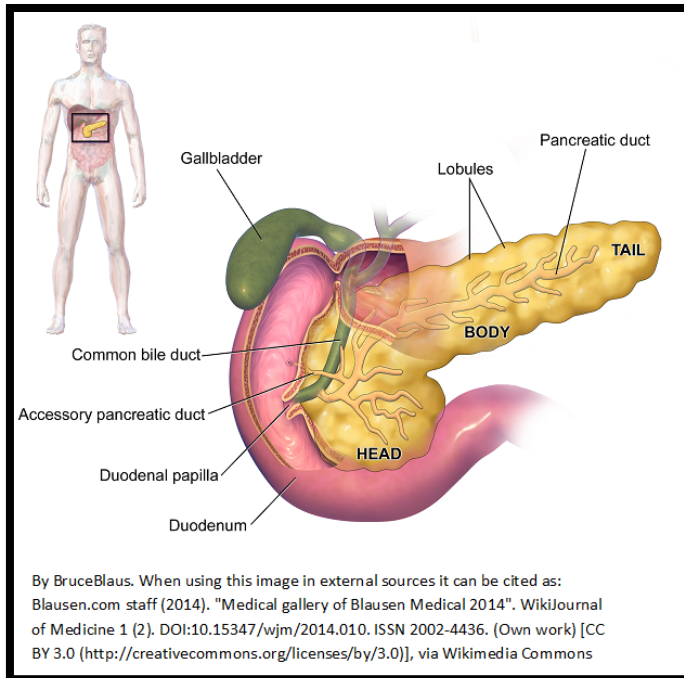
The two ducts are:

- a) The Common Bile Duct
- b) Pancreatic Duct

★ The pyloric sphincter is a band of smooth muscle that acts as a valve to control the flow of chyme from the stomach to the small intestine.



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Duodenal hormones include:

- 1) **Gastrin:** triggers secretion of HCl by parietal cells. Parietal cells have receptors for gastrin, histamine, and acetylcholine. Binding of these signaling molecules to their respective receptors cause the production and release of HCl.
- 2) **Secretin:** stimulates HCO_3^- (bicarbonate) release from the pancreatic fluid
- 3) **Cholecystikinin:** stimulates gall bladder contraction

Know these three for the DAT- a sure bet.

Other hormones such as VIP... vasoactive intestinal peptide are made by the duodenum. VIP increases peristalsis, which are recurring waves of contraction and relaxation in the smooth muscles lining the GI tract that push food along.

VIP also is involved with simulating the elimination of ions and H₂O by the GI tract.

The surface of the small intestine is modified to increase its surface area.

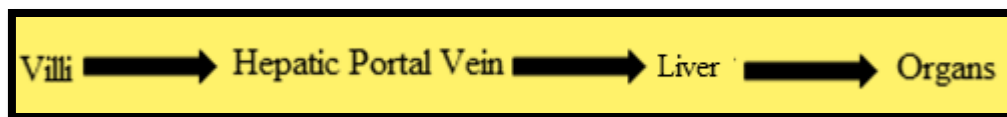
One important modification are finger-like projections called **villi**. These structures give the small intestine a “velvety” appearance and increase the surface area of the small intestine by a factor of 10.

On the surface of villi, we find **microvilli** which is sometimes called the **brush border**.

Nutrient absorption is now enhanced by this villi-microvilli system.

Internally, each villus contains a lacteal. Triglycerides are made into water-soluble globules called **chylomicrons**. Chylomicrons are fats coated with proteins, cholesterol, and phospholipids. Chylomicrons are transported to the lacteal and to the lymphatic system.

★ From the villi, the nutrient rich blood enters the **hepatic portal vein** that goes directly to the liver.



Know this path for the DAT!!

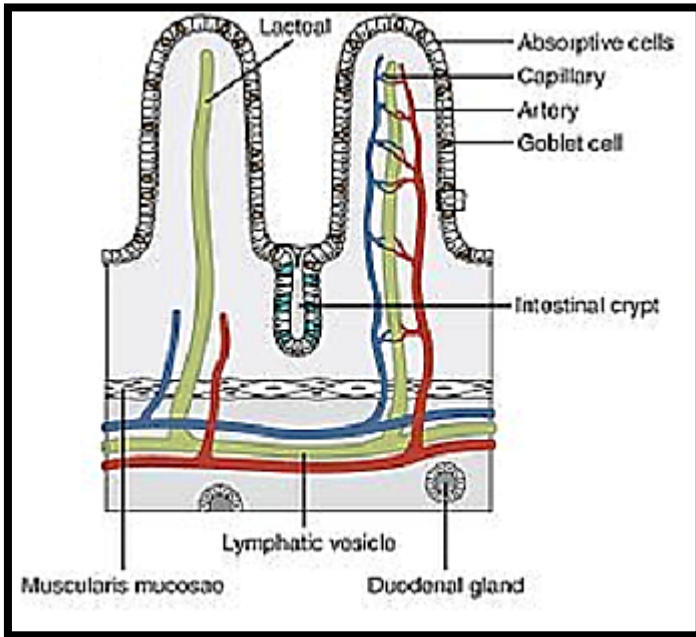
The liver gets first “crack” and what is coming in. Toxic substances can be removed, and much of the nutritive food stuff can be converted into glycogen. Glucose is released when required.

★ These villi are just one cell thick

Between the villi are invaginations called Crypts. These crypts are actually glands. These crypts, “crypts of Lieberkuhn” contain goblet cells (mucus producing), enteroendocrine cells (hormone making), and regenerative cells. At the bottom of the crypts of Lieberkuhn are Paneth cells. Paneth cells make lysozyme, contributing to maintenance of the GI bacteria by helping to destroy micro-organism. **I keep forgetting to put this question in the Destroyer- maybe next year!**

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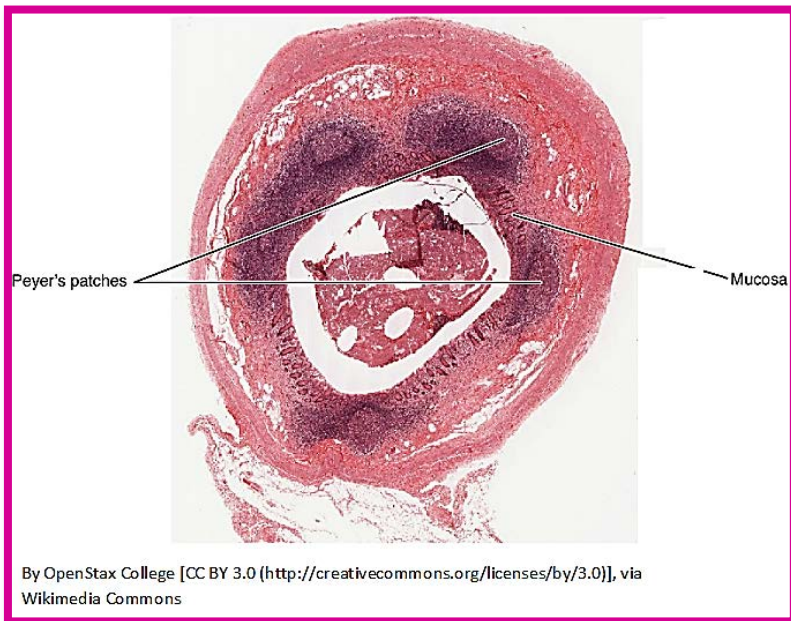
Make sure you do every Destroyer problem and read my solutions. My students here in New York average a 25 using my notes in this Bio section. Questions? Join my DAT Destroyer Study Group on Facebook... I spearhead the group.



Peyer's Patches: an aggregation of lymphoid tissue is noted in the ileum wall. (Villi are the shortest, narrowest, and sparsest here).

Peyer's patches monitor intestinal bacteria and prevents the growth of pathogenic bacteria.

They look like round balls of lymphatic tissue. Here is a histology slide.



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Peyer's patches contain the usual crew:

- a) Macrophages
- b) Dendritic cells
- c) B-lymphocytes and T-lymphocytes

Peyer's patches are part of GALT, if you recall stands for Gut-Associated Lymphoid tissue.

★ If the intestinal mucosa becomes irritated by toxic substances, swift peristaltic contractions called the peristaltic rush can occur. Normal peristaltic time and mechanism is disturbed, and strong contractions can propel the chyme within minutes for elimination as diarrhea.

Jejunum

From the duodenum, we move the chyme to the jejunum. Villi are also found here. Absorption of nutrients continue. The villi of the jejunum are longer than these found in the duodenum. Similar to the duodenum, Paneth cells are found within the crypts of Lieberkuhn. The enzymes that were released into the duodenum (ie. pancreatic lipase, pancreatic amylase, pancreatic protease) are still active in the jejunum. From the jejunum, we move to the ileum.

Ileum

Amino acids, bile salts, vitamin B-12, absorption occurs. Peyer's patches are here!

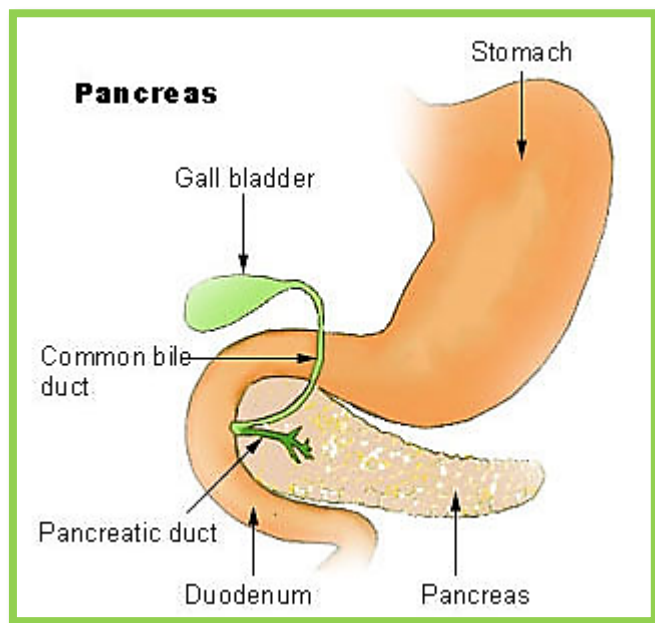
No clear demarcation between jejunum and ileum; they merge gradually.

The ileum is separated from the first part of the large intestine by the **ileocecal valve**.

Before we examine the fate of undigested food, let us look at the **accessory digestive organs**. Besides the tongue, and salivary glands already discussed, we have the liver, pancreas, and gall bladder.

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Pancreas



This is a **dual organ**. It has endocrine and exocrine functions.

This organ is about 5 inches and lies behind the stomach and extends across (transversely) the upper abdomen. Recall, as an endocrine gland, it makes: insulin, glucagon, somatostatin (inhibits insulin and glucagon secretion).

The digestive enzymes are produced by the exocrine portion, while the hormones are produced by the “islets of Langerhans”.

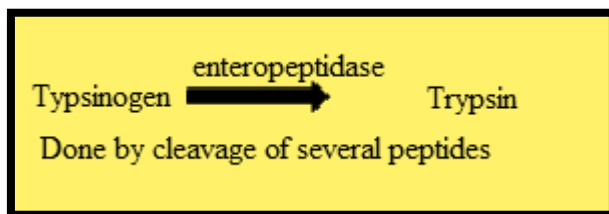
About 2 L of pancreatic juice/day is made. Pancreatic juice contains:

1. HCO_3^-
2. Proteases (trypsin, chymotrypsin, procarboxypeptidase) **favorite DAT question!!**
3. Amylases
4. Lipases
5. Nucleases (digest DNA and RNA)
6. Elastase

★ The proteases such as trypsin and chymotrypsin are stored as zymogens. They are cleaved and activated by **enterokinase** in the intestine.

This is important. Why? It prevents the pancreas from digesting itself.

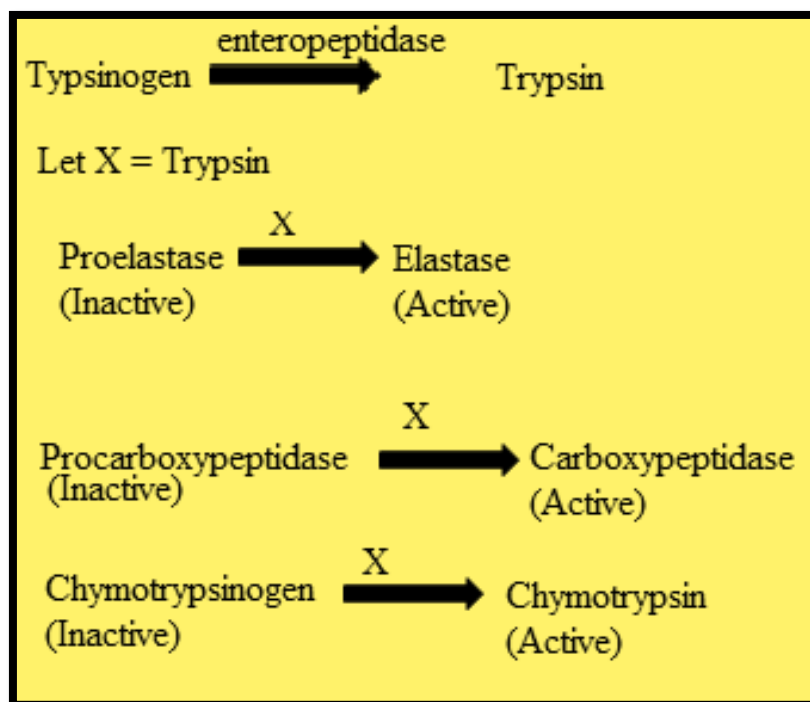
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★ Enterokinase is believed to be made by the Brunner glands of the duodenum.

Now... here is the crazy, insane part, trypsin can now activate the other zymogens by **proteolytic cleavages**. This is a cascade, and is seen often when enzymes are activated by what is called covalent modification.

Summary



Pancreatic secretion is under the control of two hormones mainly:

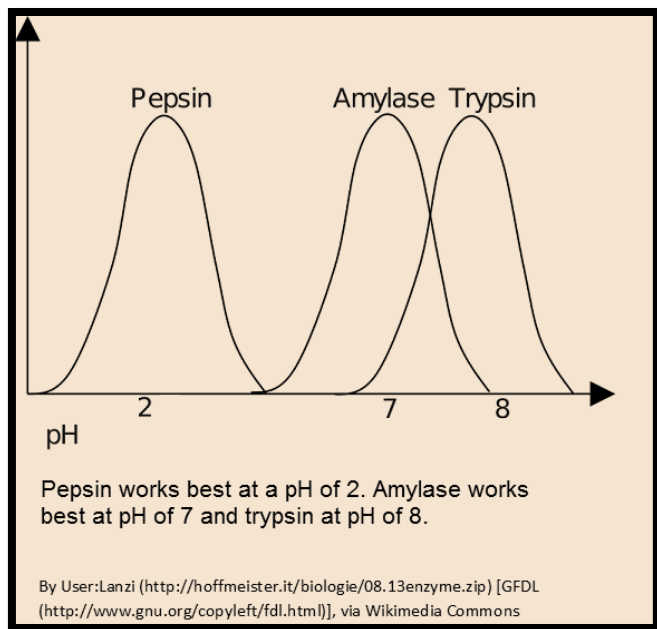
- 1) CCK (cholecystokinin)
- 2) Secretin

Acid and chyme enters the duodenum and stimulates the release of CCK and secretin.

Secretin is needed to make the pancreatic juice alkaline. This fluid neutralizes the acidic chyme and allows the pancreatic enzymes to function at this optimal pH range.

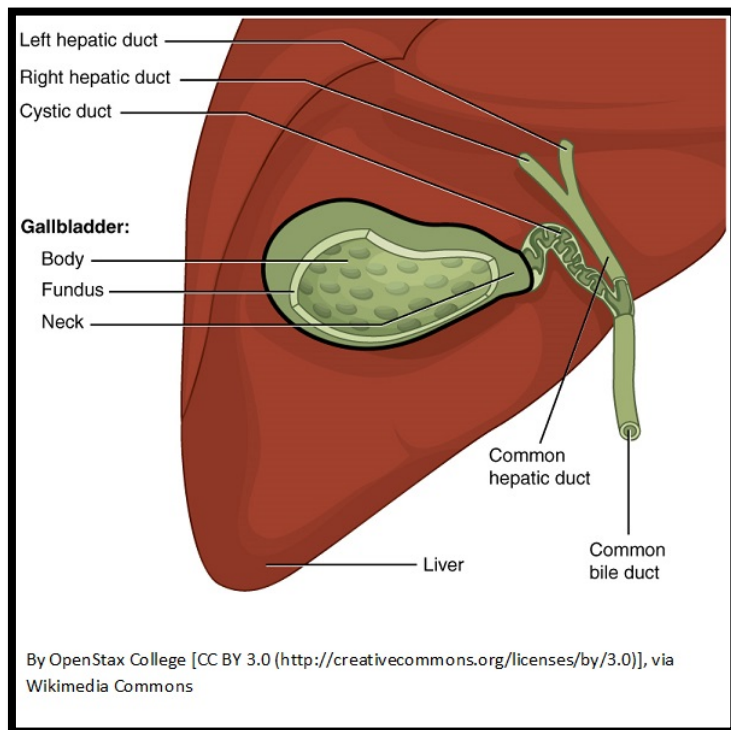
Enzymes have different profile graphs. For example:

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This is very important for you guys to understand as you move forward in your scientific journey!

Gall Bladder



Bile is **stored and concentrated** here.

Bile enters the duodenum via the **common bile duct**.

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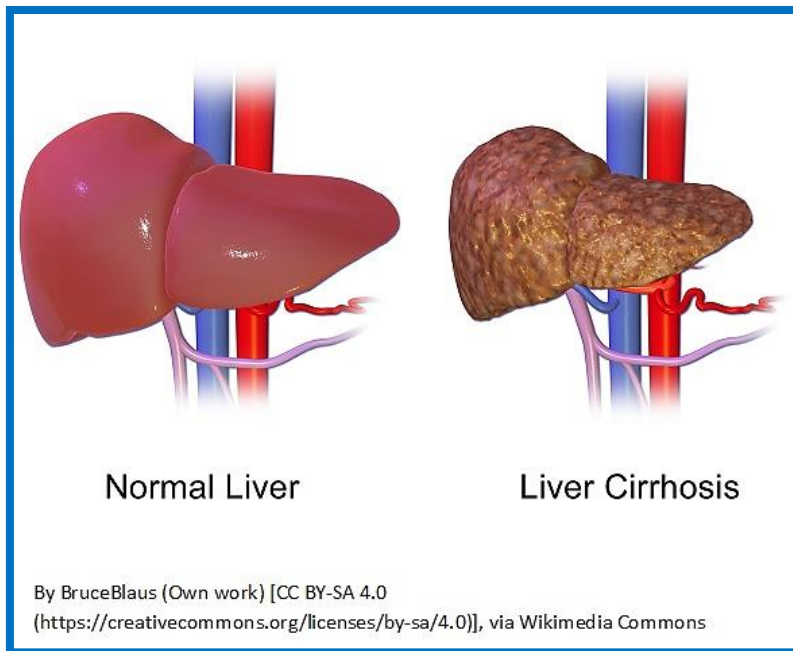
The organ is only about 4 inches in length and 1.5 inches in cross section and can store about 70mL of bile. It resembles a sac.

CCK triggers the release of bile. In addition, acetylcholine released by parasympathetic fibers from the vagus nerve which also stimulates gall bladder contraction.

You might have known a person with gallstones. The proper term is cholelithiasis. Many gallstones are small and most people are not even aware they have them. 80% of their composition is cholesterol. The bile of people with gallstones have more cholesterol as it leaves the liver, thus showing that the liver is the likely culprit for the birth of gallstones.

For those curious, cancer of the gallbladder can occur, with a 5-year survival rate, 2%. By the time it is diagnosed, metastasis to sites such as the liver occurs.

Liver



The **largest internal organ**. Skin is the largest organ, however!!

This organ can **regenerate**. This is a fundamental response to injury. Hepatocytes (liver cells) begin to divide in response to toxic substances. This is called compensatory hyperplasia. The hepatocytes live about 150 days. New cells are made until the original tissue size is restored to normal.

A layer of connective tissue called Glisson's capsule surrounds the liver.

The liver has many functions including:

1. Makes bile and cholesterol

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2. Drug detoxification
3. Produces plasma proteins (albumin, fibrinogen, for example)
4. Vitamin storage (Vitamin A is stored in greatest amount)
5. Deamination of proteins (Removal of NH_2 group)
6. Chylomicrons are broken down into glycerol and fatty acids
7. Makes 90% of blood proteins
8. Stores glycogen and releases glycogen (glycogenolysis) and gives glucose to be transported to the body. Iron storage too!
9. Urea production, it converts NH_3 into urea. NH_3 comes from two sources: amino acid deamination and bacterial action in the GI tract
10. Along with the spleen, it is involved with disposing of red blood cells. It is still debated by PhD scientists which organ: liver or spleen is more involved!

I listed a few. At least 90 more remain!!

Let us look at **bile**:

- a) Bile is an emulsifier of lipids
- b) Bile is not an enzyme
- c) Bile contains cholesterol, bile salts, bilirubin (pigment), phospholipids, water, and even IgA

Bilirubin is a yellow-green pigment and formed when red blood cells are destroyed.

Macrophages are in the spleen and liver. In the liver, the macrophages are called Kupffer cells, destroy the red blood cell. Bilirubin is released into the bloodstream and is bound to albumin.

When circulating bilirubin levels are high in the blood during many liver diseases, a yellowish discoloration of the skin occurs. This is called **jaundice**.

In hepatitis (inflammation of the liver), this can occur. Increased hemolysis of red blood cells also can cause jaundice. The bilirubin cannot be removed rapidly enough.

Recall, the blood from the villi entered the hepatic portal vein. Blood from this area may harbor pathogenic organisms. The Kupffer cells phagocytize 99% of the pathogens, along with destroying defunct red blood cells.

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Liver Blood Supply

- a) **Hepatic portal vein** or just portal vein: brings blood to the liver from the villi
- b) **Hepatic vein**: transports deoxygenated blood away from the liver to the inferior vena cava
- c) **Hepatic artery**: carries oxygenated blood to the liver

Very important vessels to know for the DAT exam.

The hepatocyte is responsible for converting lipids and amino acids into glucose. This process, if you recall, was called **gluconeogenesis**.

Thus 2 big DAT questions loom...

Gluconeogenesis and deamination will occur in the hepatocyte. Feel free to stop at this point and Google a histology slide of the liver. I want you to look at the large polyhedral cells with six or more sides called **hepatocytes**.

Hepatocytes have two or more nuclei!! 50% of them are polyploid with 4,8, even 16 times the haploid chromosome complement. I kid you not. Human liver cells are highly aneuploid. Why? I have read many PhD papers on this, and the answer remains a mystery.

What is cirrhosis?

This is a consequence of a sustained injury to hepatocytes. Drugs, alcohol, even the hepatitis virus cause injury. Fibrous tissue replaces the normal hepatic architecture. This is very common, but not restricted to alcoholics.

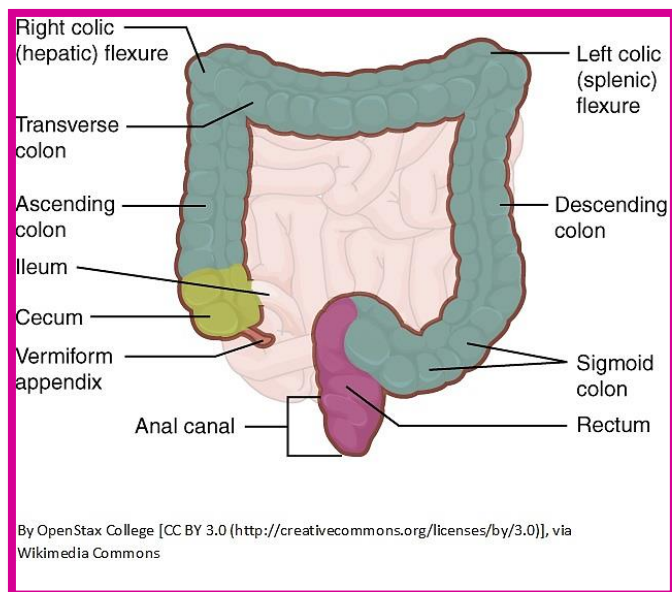
If you look under the microscope, you will see what is called the **portal triad**.

The portal triad includes:

- 1) Portal Vein
- 2) Hepatic Artery
- 3) Bile Duct

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Large Intestine (Colon)



Stores waste

Absorbs H₂O

Produces mucus that lubricates the intestinal surface

It is divided into six regions:

- 1) Cecum
- 2) Ascending colon
- 3) Transverse colon
- 4) Descending colon
- 5) Sigmoid colon
- 6) Rectum

No villi are present!!

Recall, the **ileocecal valve** regulates the flow of intestinal contents into the cecum.

The **appendix** is an evagination of the cecum. It has no digestive function, but studies have shown that it is part of MALT (mucosa-associated lymphoid tissue). Many books call it a “**vestigial organ**”- meaning it has lost all or most of its original function through evolution. However, much evidence has surfaced that points to the appendix having an immune function, during the early years of life. Research has shown it aids in the maturation of B lymphocytes, as well as in the production of antibodies. By age 60, it has virtually no function.

I have also recently seen a paper that suggested the appendix might also serve as a reservoir for “good guy bacteria”.

The large intestine absorbs vitamins such as Vitamin K, which is created by bacteria of the large intestine. A great example of mutualism!

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Over 400 bacteria are housed by the large intestine. Biotin is also made by these bacteria. 99% of the bacterial species residing in the large intestine are obligate anaerobic bacteria. Clearly you see that health is depending on the symbiotic relationships among the different microbiota.

Besides bacteria, which dominate the community, fungi, protozoa, and virus are also seen.

Fecal matter accumulates in the **rectum** and is eliminated out of the **anus**. Feces is $\frac{3}{4}$ H₂O and $\frac{1}{4}$ solid matter with bacteria.

★ The small and large intestine absorb about 90% of the H₂O that enters the GI tract.

Recall a **ruminant**. A ruminant such as a cow or goat can digest cellulose. There is much energy in cellulose, but we as humans cannot digest cellulose. The cellulose molecule has a β -1,4- linkage.

Cow's guts are packed with bacteria, fungi, and protozoa. The microorganism can digest cellulose. The exact mechanism behind this is not straightforward, and is still being studied.

The ruminant bacteria are obligate anaerobic in nature, that include clostridia, and bacterioidetes.



Bottom Line: Ruminants contain microorganisms which actually break down the cellulose. They do this with enzymes. Without the microorganisms, the ruminant would be unable to break down cellulose.

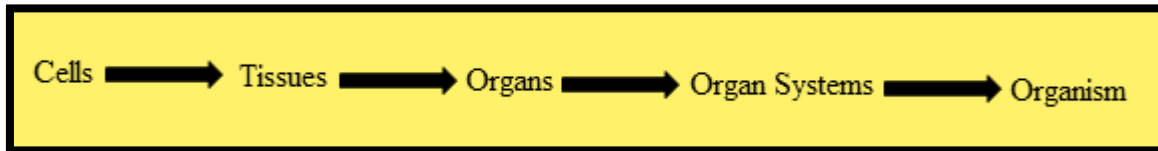
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Homeostasis

This refers to the dynamic steady state that is maintained within the organism.

I have presented many systems to you including the circulatory, excretory, digestive, respiratory, skeletal, etc.

There is a hierarchy if you recall:



Recall our four tissue types:

- 1) Epithelial: protection, absorption, secretion
- 2) Muscle: contraction and movement
- 3) Nervous: sensory and response functions
- 4) Connective: supportive (e.g. blood, bone, ligaments, tendons with scattered cells in an extracellular matrix)

All systems must act in a **coordinated** manner if homeostasis is to be maintained.

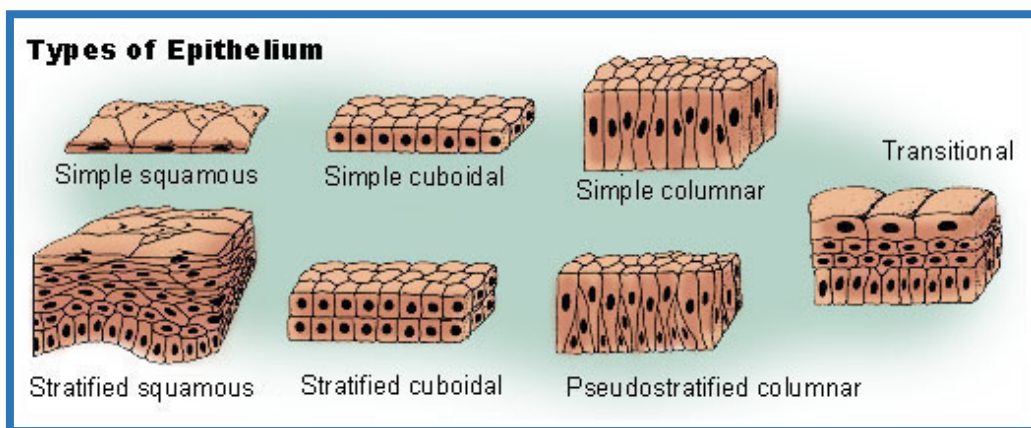
There are **different types of epithelial tissue**:

Cuboidal: e.g. many glands and kidney tubules, think secretion!!

Simple columnar: e.g. much of the GI tract (protection, lubrication, absorption, and even secretion!!)

Simple Squamous: lines blood vessels, alveoli, loop of Henle, pleural and peritoneal cavities. For exchange of materials, thin and leaky!

Stratified Squamous: epidermis, esophagus, vagina, anus. Regenerates rapidly, found on tissues subject to abrasion



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For the DAT, just be able to recognize these three cell types and that should suffice.

Let us review **connective tissue fibers**:

Collagen Fibers

In the living individual, they appear white and are also called white fibers. They are very rich in glycine, 33% of the amino acid content of collagen is glycine, a small optically inactive amino acid.

It has a **triple helix** (tropocollagen)

Many different types of collagen exist. Collagens constitute a family of proteins. They are fibrous proteins and hydrophobic.

Hydrogen bonding and cross linking occurs through a series of complex reactions between lysine and histidine residues.

In bone and teeth, collagen is embedded in hydroxyapatite, an inorganic calcium phosphate polymer which gives it strength.

Tendons, dentin, dermis, ligaments, and organs all contain collagen.

Hydroxyglycine and hydroxyproline are seen in the polypeptide chains.

Several genes are involved with collagen biosynthesis; thus, a large number of diseases could result from a defect in collagen synthesis.

Scurvy, Ehlers-Danlos, and Osteogenesis Imperfecta are some examples, the details of which we do not need for the DAT, but you will study in grad school.

Vitamin C is needed for proper collagen synthesis, and a lack of this vitamin may give rise to scurvy. Proline cannot be hydroxylated, thus the tropocollagen molecules cannot form a stable helix.

In Ehlers-Danlos syndrome we see hyper- extensive skin and hypermobile joints which can easily become traumatized.

Elastic Fibers

Unlike collagen, these fibers are very accommodating and can be stretched quite far without breaking. They have the ability to recoil.

Made by fibroblasts and smooth muscle cells in arteries.

Allows our skin to return to its original position if pinched.

Highly abundant in blood vessels such as the aorta.

Also found in the bladder, lungs, veins, ligaments, cartilage, and skin.

Easily hydrolyzed by the pancreatic enzyme elastase.

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Reticular Fibers

Give support to individual cells

Very thin, branched fibers, made of collagen. When you go to histology class, you will easily see them because they stain black because they react with silver salts (argyrophilic).

Found in high % in: smooth muscle, lymph nodes, spleen, red bone marrow

Connective Tissues Include

- a) Adipose
- b) Blood
- c) Bone
- d) Cartilage

★ **Fibroblast cells** are huge players in this biochemistry game. They synthesize proteins like elastin and collagen, glycoproteins, proteoglycans, and glycoproteins of the extracellular matrix, as well as growth factors that influence cell growth and differentiation.

In adults, the fibroblast does very little mitosis, however will divide when more fibroblasts are needed.

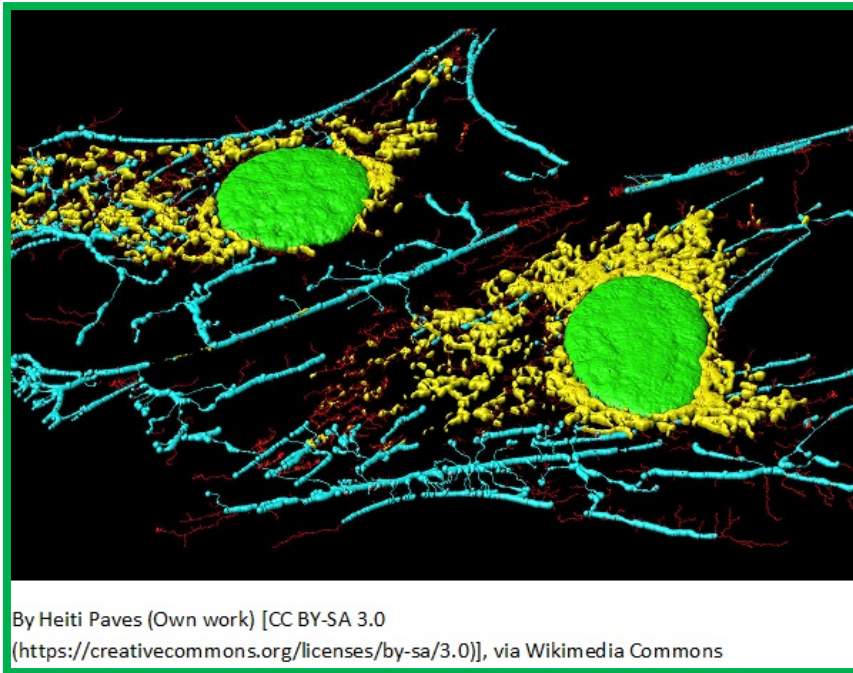
When a tissue is destroyed by trauma or by pathology, the spaces left are usually filled in by connective tissue, we call it a scar.

Who do you think is our main repair cell?

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Yes, indeed, the fibroblast!

A few fibroblasts, just for you:



Fibroblasts are the most abundant cell in connective tissue. They make almost all of the **extracellular matrix**. The extracellular matrix surrounds the cells as a noncellular component. It provides support, but also guides division, growth, and cell development.

Fibroblasts also make **fibronectin**. Fibronectin attaches the extracellular matrix to the cell surface receptor protein such as integrins. The Campbell textbook has a great picture of this and you will easily understand this connection.

Fibronectin is directly involved with wound healing. We need not go into the details, but understand that fibronectin migrates into a clot and aids in repair.

Nervous Tissue

Stimuli from the environment is transmitted in the form of nerve impulses.

We reviewed this when we discussed the nervous system.

Contained neurons along with those cells that helped nourish and replenish neurons called glial cells or glia.

Control and coordination, if you recall, are involved in two main systems: nervous and endocrine.

Bottom Line:

- 1) Endocrine: hormones secreted directly into the bloodstream but targets specific cells that have the proper receptors (**Favorite DAT question!**). Hormones are relatively slow acting and can remain in the blood for a few second to a few hours!!

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- 2) Nervous: transmits information along a specific “communication line” called a neuron. Much faster than endocrine and lasts for a very brief amount of time.

Endocrine and nervous systems differ in:

- a) Speed and duration
- b) Hormone or nerve impulse signal
- c) Transmission

However, both work together to establish homeostasis.

Recall, we examined feedback mechanisms. Some feedback systems that decrease a hormone level for example, are negative. Other feedback systems may increase a hormone level and that was a positive feedback system. Both are needed for homeostasis.

Thermoregulation

Many animals make physiological adjustments as temperature changes within their environment. Acclimatization is a physiological adjustment to changes in the external environment.

Animals need to maintain an internal body temperature that will allow their physiological processes to occur. As a general rule of thumb, a reaction rate will double for every 10°C change in temperature.

The sum total of all cellular activities in the body is termed metabolism. Metabolic rate changes with the degree and level of activity that an organism takes part in.

Let us examine endotherms and ectotherms **(a favorite DAT topic!)**:

Endotherms	Ectotherms
They are warmed mainly by metabolism	They are warmed mainly by external sources from the environment.
Commonly called “warm-blooded” but this term has been dropped	Commonly called “cold-blooded” but this is not really correct. The blood varies with the ambient temperature.
Birds and mammals	Amphibians, many reptiles, many fish, and most invertebrates
Cells usually have more mitochondria	Many reptiles regulate their body temperature by basking in the sun or even relaxing in the shade
Usually require more food than ectotherms due to their higher metabolism	Because their heat source is mainly from the environment, they consume less food
	Can tolerate temperature changes

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Now for the confusing part:

- a) **Homeotherm:** constant body temperature
- b) **Poikilotherm:** body temperature varies with environment

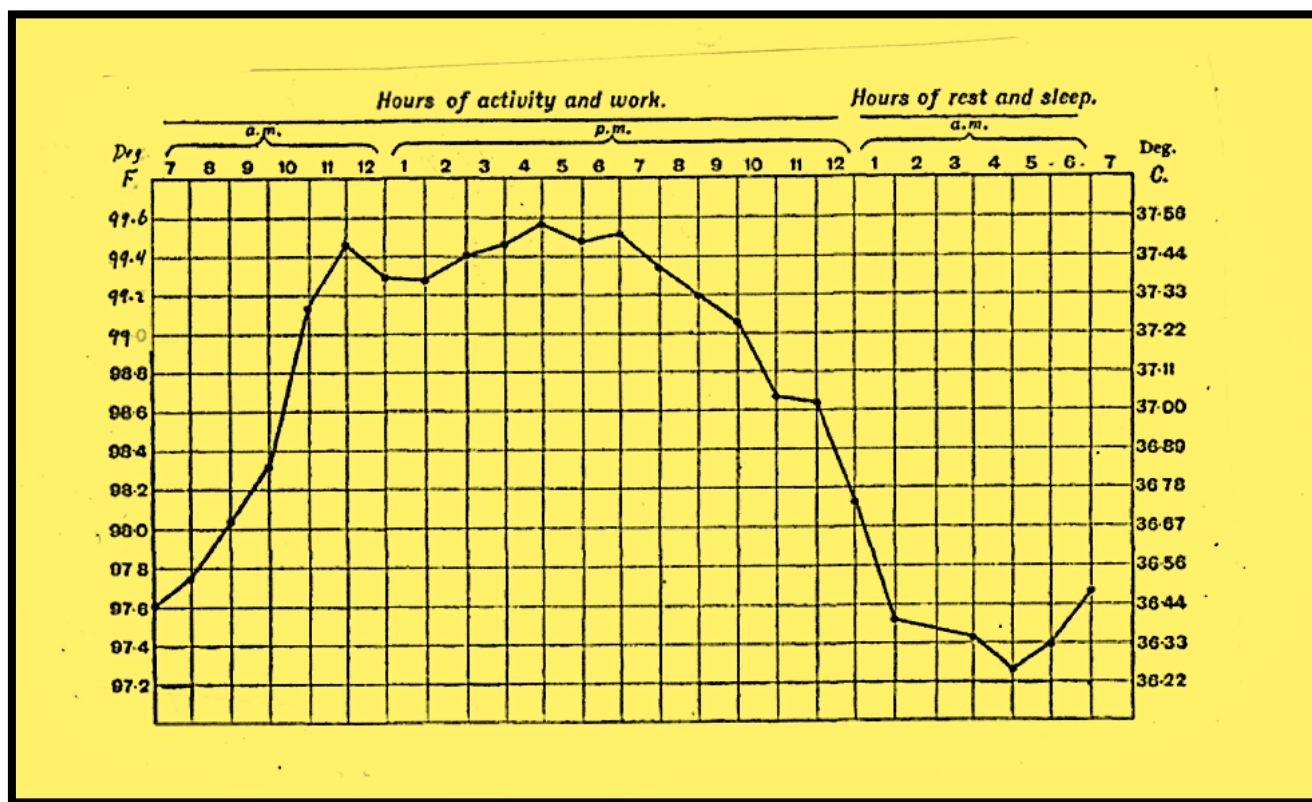
Most endotherms are homeotherms and most ectotherms are poikilotherms but not all. eg. some marine fish are ectotherms but their body temperature does not vary much. As a matter of fact, it varies less than you or I!!

Thus, I simply suggest that we keep the terms separate.

Bats, by the way are mammals, yes? They are endotherms. They sometimes enter a dormant state in which their body temperature is not what we'd expect for a homeotherm, their body temperature drops quite low.

In humans, body temperature average is 37°C or 98.6°F.

Recall $F = 1.8C + 32$ and $K = C + 273$, **two essentials for general chemistry.**



Body temperature depends on many factors such as time of day, exertion, sex, age, and your emotional state.

When cold, we shiver, which is a series of involuntary muscle contractions that help produce heat, even the jaws get into the action as our teeth “chatter”.

When hot, we sweat. The evaporation that occurs rids the body of a great deal of heat.

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Thus, as you see shivering and sweating both require energy and raise our metabolic rate.

Mammals and birds have a very important thermoregulatory adaptation, and that is insulation. Heat flow is reduced between animal and environment by:

- 1) Hair
- 2) Fat: our main insulation!
- 3) Feathers

A blood vessel may increase blood flow if it undergoes a vasodilation. In endotherms, this will usually warm the skin. Vasoconstriction of a blood vessel will reduce blood flow and act as a cooling mechanism.

Sweat glands secrete sweat which evaporates to help cool the body. Sweat glands and capillaries are quite vital to thermoregulation. (These capillaries fill with warm blood upon vasodilation and this heat radiates from the surface of the skin, like when you are playing basketball and your face looks red... this is thermoregulation!).

Body Size and Metabolic Rate

Careful here!! This just might go against common sense.

As we increase body size, we decrease metabolic rate.

For endotherms, a small body mass means the surface-to-volume ratio is high and the faster it loses heat. It must therefore maintain a high metabolic rate to fuel the cellular oxidative processes. This area is still in debate, however. For the most part, this inverse relationship is also noted in ectotherms even though they do not use heat from metabolic reactions.

The smaller animal has a higher breathing rate, heart rate, and blood volume relative to its size.

Bottom Line: Smaller animals tend to have higher per-gram basal metabolic rates than larger animals

Some mammals can let their body temperature and metabolism decrease for long periods of time. This adaptation to cold and scarcity of food is called **hibernation**. These animals survive on the metabolic reserves that it accumulated before entering hibernation. Heart rate, body temperature, and O₂ consumption may fall dramatically. Bears, for example, can use accumulated fat deposits and “burn” this fat during hibernation.

Bears are not the only animal that hibernate. Hummingbirds, turtles, groundhogs, bumblebees, bats, ladybugs, and even skunks!! (Skunks smell bad mainly due to compounds called thiols in their spray).

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Plants



Autotrophic organisms which are able to synthesize all required organic compounds from inorganic substances using an energy source, namely sunlight.

Multicelled and eukaryotic

Evolved from green aquatic algae about 500 million years ago.

Over a quarter million plant species are known today and are found in many diverse regions... from desert areas to polar areas, plants thrive.

Have cell walls made of cellulose (β -glucose linkage)

Vascular Plants

Have distinctive areas of **specialized tissue** such as xylem and phloem.

Xylem: conducts water and minerals from roots to the rest of the plant in one direction.

Phloem: carries sugar from leaves to the rest of the plant

The xylem contains cells called **tracheids**, thus are called tracheophytes. Another xylem cell is called a **vessel member**. Both of these cells are dead at maturity. Xylem also aids in supporting the plant.

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In phloem, the main conducting cells are called **sieve-tube members**. Sugars that are made by photosynthetic leaves are loaded into these tube members with the help of companion cells. Sugars then are unloaded for growth or storage.

Plants use the products of photosynthesis (which was discussed earlier in these lecture notes) to synthesize all the organic compounds they need for their structure and function.

★ Xylem transports up, phloem can transport up or down as needed.

★ Xylem is what makes up wood ★ Think xylem rings!!

Leaf surfaces are protected against water loss by a **cuticle**. The cuticle is a waxy coating, thus is hydrophobic. It is also impermeable to CO₂... thus when CO₂ enters, the special regulated openings called **stomata** allow the CO₂ to diffuse through. CO₂ must combine with water before absorbed by leaf cells. Water is used in growth and metabolism, but most evaporates into the air. H₂O evaporation in plants is termed **transpiration**.

★ In most plants, the stomata stay open during daylight when photosynthesis occurs. CO₂ can enter; H₂O is lost.

At night... stomata are closed... CO₂ accumulates and water is conserved.

(★ Flanking the stomata are **guard cells**. When water builds up, they become swollen and open up... this allows water vapor loss and CO₂ entry in the leaf in the day).

Aeration and H₂O-holding capacity will determine if the soil is suited for plant growth. Let's talk about roots.

Roots

Specialized structures that most often grow downward

Absorbs H₂O and minerals

Anchors the plants

Stores food and releases it as needed

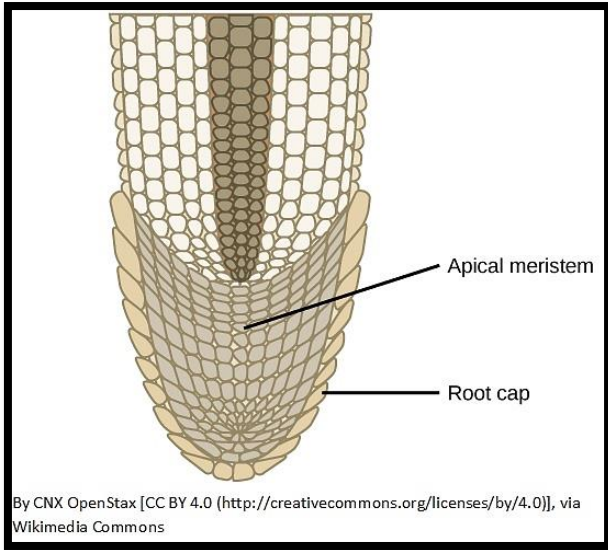
All begin with a single root (primary root), but then grow differently into smaller roots (secondary roots).

Root surface area is increased enormously by outgrowths called **root hairs**. I have seen a study where a scientist estimated a plant had roots over 375 miles long!

At the root tip = **meristem**

Chapter 36- Plants

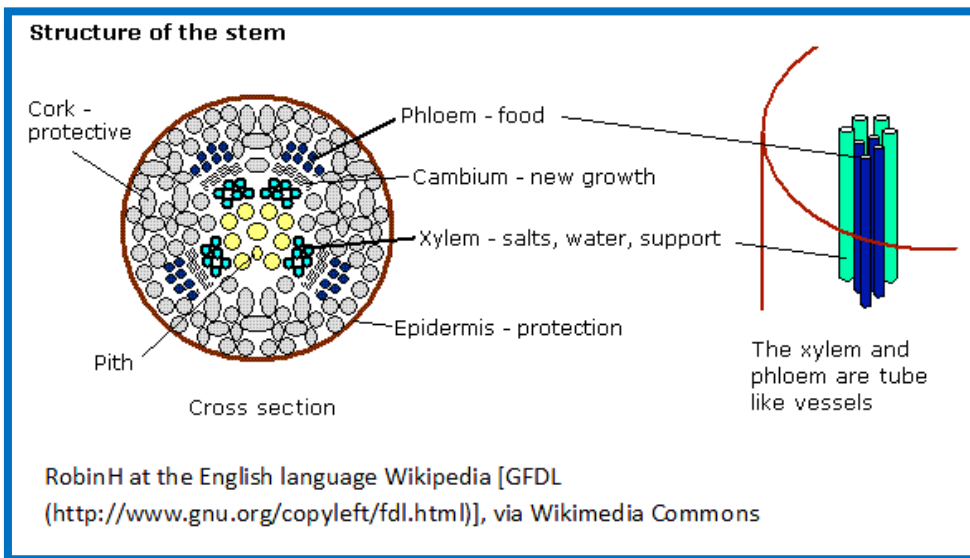
Here is an area of active cell division, we see new plants grow and older plants lengthen.



Note the progressive cell specialization in this picture of a root tip.

Roots contain many structures such as:

- A) Epidermis:** outermost layer which includes the root hairs
- B) Cortex:** stores starch; contains parenchymal cells
- C) Endodermis:** innermost layer of cortex associated with a waxy tissue band called a Casparian strip. This strip is involved with controlling the uptake of water and dissolved nutrients.
- D) Stele:** Layer of cells inside the epidermis containing xylem and phloem cells. This is also called the vascular cylinder. Cambium tissue lies between the xylem and phloem, and will add more layers of xylem and phloem to thereby thicken the root. The outer part of the stele is a layer of cells called a pericycle. These cells can initiate the development of secondary roots.



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★ On the roots of legumes such as peas and beans, we see swellings called **root nodules** that contain the nitrogen-fixing bacteria which convert atmospheric N_2 into forms required by the plant, such as NO_3^- and NH_4^+ .



Once NO_3^- and NH_4^+ are absorbed by the plant, they can use them to form amino acids, proteins, and other nitrogenous compounds.

Soil microorganisms can also break down dead organisms to release NH_4^+ which can be oxidized into NO_3^- in a process called **nitrification**.

In **denitrification** we form N_2 and a small amount of N_2O as NO_3^- and NO_2^- are converted into these products. This is all part of what is called the **nitrogen cycle**.

The bottom line is that biological nitrogen fixation as well as decay, give the soil usable nitrogen compounds for fertility.

A fungi: can also be associated with a root symbiotically like the nitrogen-fixing bacteria.

Mycorrhizae: this is the association of a nonpathogenic fungi with roots. Materials absorbed by the plant passes first through the fungi which allows them to gain nutrients. The fungus actually increases the surface area available for water and nutrient uptake. Some trees grow poorly without the fungus present!!

Orchids are among the plants that also depend on this symbiotic relationship called mutualism.

Dermal Tissue

Besides vascular tissue (xylem and phloem) we also have dermal tissue.

Dermal tissue **covers and gives the plant protection**. H_2O loss is restricted by the cuticle.

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The **epidermis** is a layer of tightly packed cells that covers the primary plant body. It is only a single cell larger and many epidermal cells have extensions that are root hairs.

Ground Tissue

The third tissue besides vascular and dermal tissue is called ground tissue.

Three types of ground tissue which differ primarily in the cell wall structure:

Parenchyma

Collenchyma

Sclerenchyma

Parenchyma Cells:

Most abundant, thin walls seen in roots, stems, leaves, etc.

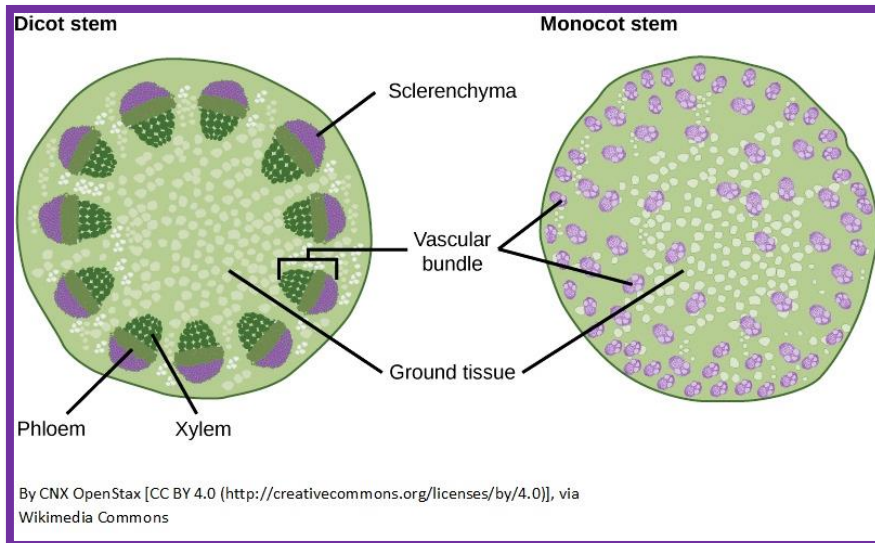
Storage, secretion, and photosynthesis involvement

Collenchyma Cells:

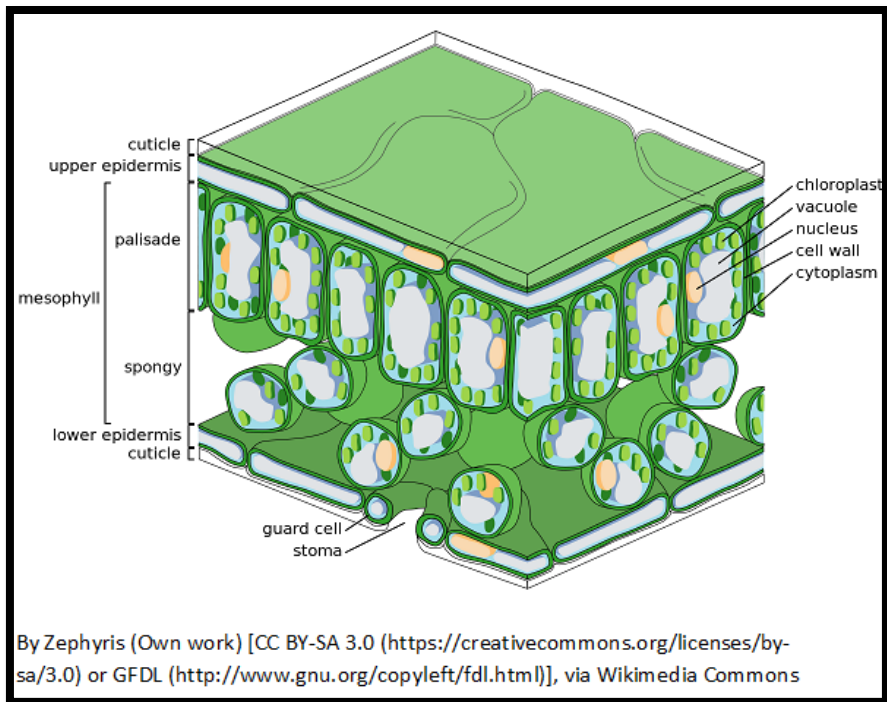
Cell's walls are thick, but imparts flexible support for the growing stem

Sclerenchyma Cells:

Very thick cell walls that provide protection and support... contain lignin... this is the 2nd most abundant natural polymer in the world, next to cellulose. Lignin and cellulose work as a team to provide strength and support. Lignin also forms a barrier against invaders like fungi or insects.



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Stems

A root system is usually beneath the ground, while a **shoot system** is above the ground as is made up of stems and leaves.

Stems will:

- A) Support shoot system structure
- B) Transport substances between roots and the leaves
- C) Store food (some carry out photosynthesis. In a cactus... this is where the main photosynthetic machine is found).

The leaf, stem, and root contain the three tissue types we discussed: vascular tissue, dermal tissue, and growth tissue.

Before we go on, let us consider two **seed plants**:

Angiosperms



The flowering plants (roses, apple trees, corn)

Pears, strawberry, cherries, raspberries, apples

Fruits-n-flowers!! Grasses, oak and maples too.

Chapter 36- Plants

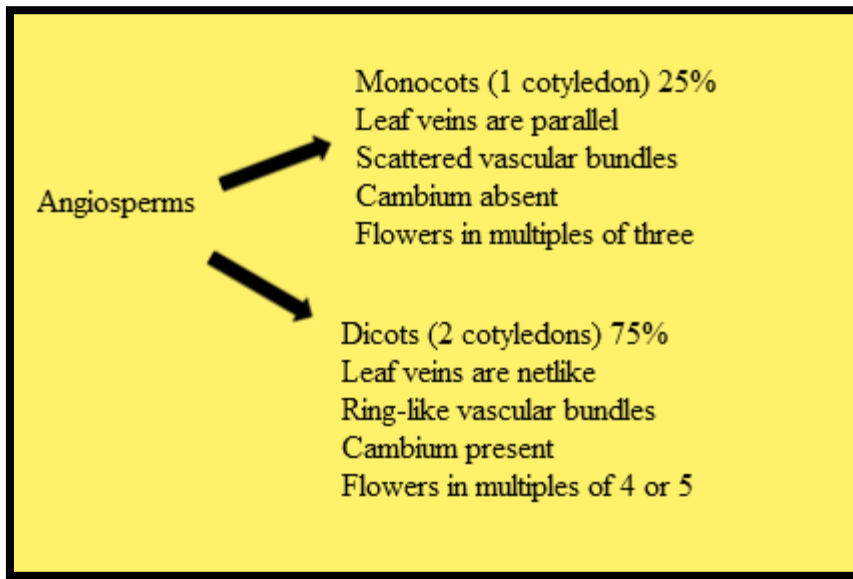
Most (90%) of plants are angiosperms

Most diverse plants

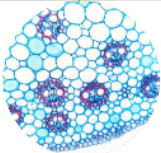
Produce seeds

As seeds develop from structures called **ovules** after fertilization, the ovary becomes the **fruit**.

Definition: **cotyledon**- a seed leaf of a plant embryo



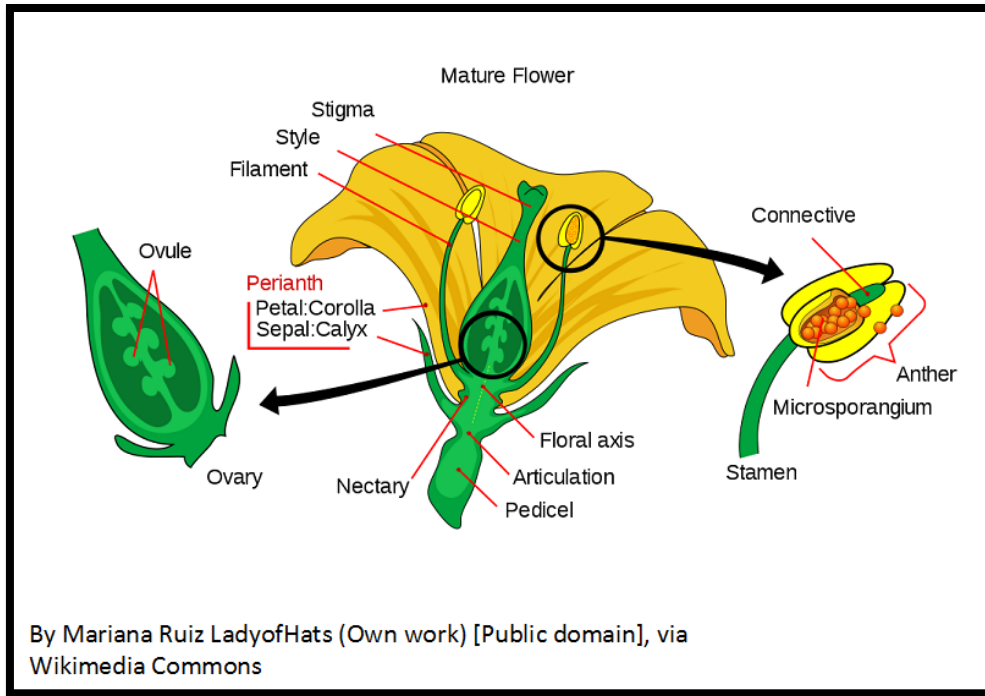
Chapter 36- Plants

MONOCOT	DICOT
Single Cotyledon 	Two Cotyledon 
Long Narrow Leaf Parallel Veins 	Broad Leaf Network of Veins 
Vascular Bundles Scattered 	Vascular Bundles in a Ring 
Floral Parts in Multiples of 3 	Floral Parts in Multiples of 4 or 5 
By Flowerpower207 (Own work) [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons	

★ **For the DAT exam, this is good enough, other differences also exist**

Since the majority of angiosperms are flowers, let us briefly touch this. **The DAT does not go into too much detail here, so I will be brief and give you the essentials:**

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Male part = **stamen**: includes:

- a) **Anther**: chamber where pollen grains develop
- b) **Filament**: a slender stalk

Female part = **carpel**: includes:

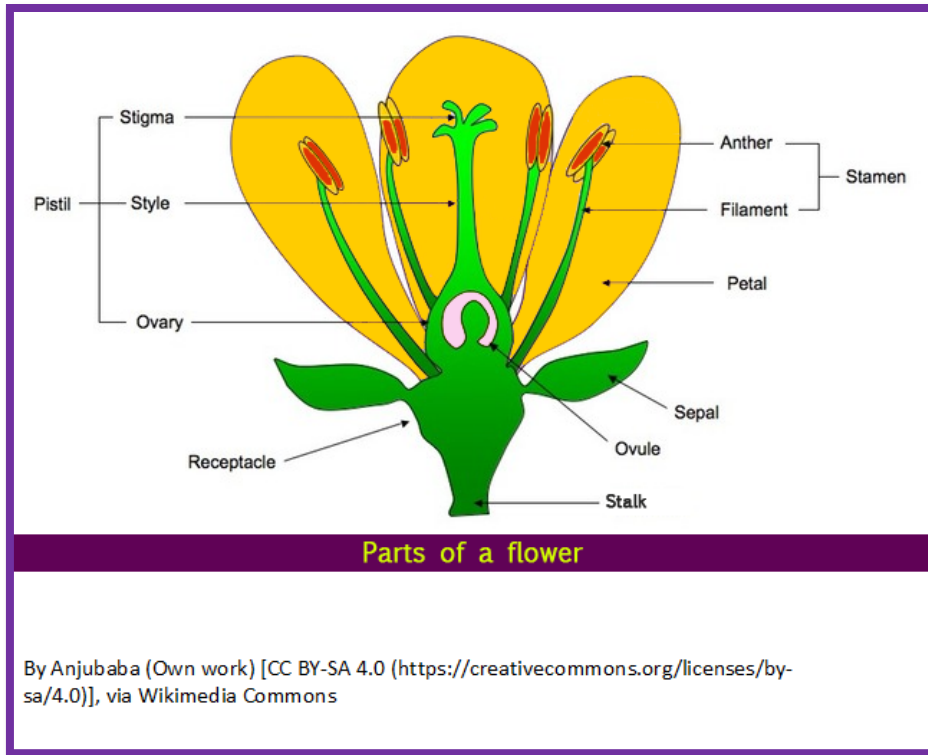
- a) **Ovary**: eggs develop, fertilization occurs, and seeds mature
- b) **Style**: a connecting stalk
- c) **Stigma**: sticky part... catches the pollen

A **petal** is the part of the flower that is usually colored. Colors attract pollinators.

A **sepal** offers protection to the flower. Collectively, the sepals are called the **calyx**. After flowering, most plants have no further use for this structure and it withers away.

The Ovule: a stalked structure that develops on the ovary wall. It consists of an egg and surrounding tissue. When mature, the ovule becomes the seed.

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★ Note: A seed is produced after fertilization by pollen.



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Bottom Line: the stigma catches the pollen, it travels down the pollen tube and then finds a receptive ovule, inside the ovary. The male and female genetic material unite to form an embryo which will become a seed.

Fruits, flowers, and what is called **double fertilization** are unique to angiosperms.

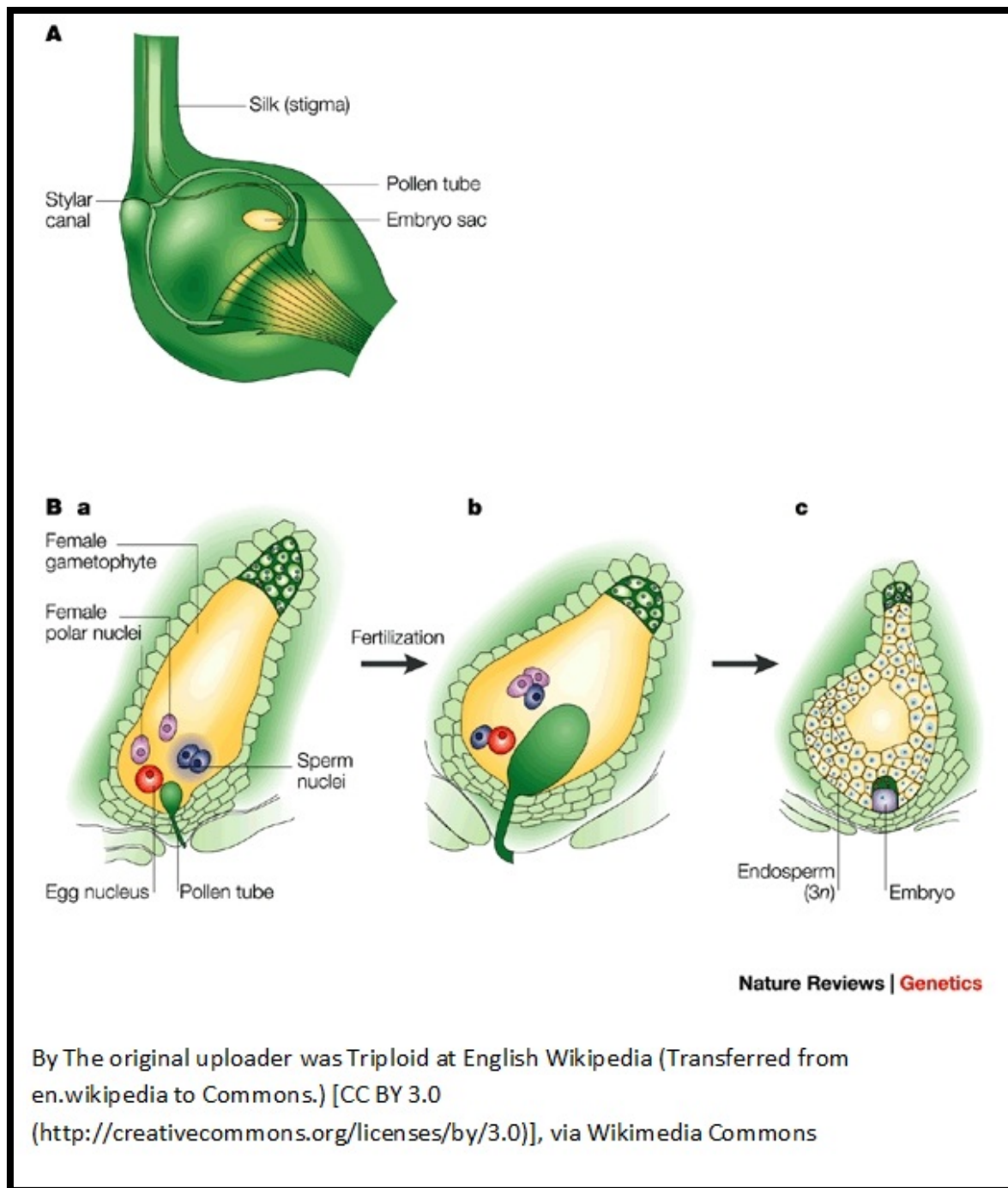
What is double fertilization?

The arrival of a pollen grain on the female reproductive part is called pollination. A pollen grain develops into a “pollen tube” which grows toward the ovary and contains two sperm.

The egg fuses with one sperm and a zygote is made (2N). The other sperm fuses with two polar nuclei cells to make a 3N cell... this 3N cell will give rise to the nutritive tissue. (The 3N tissue represents the endosperm).

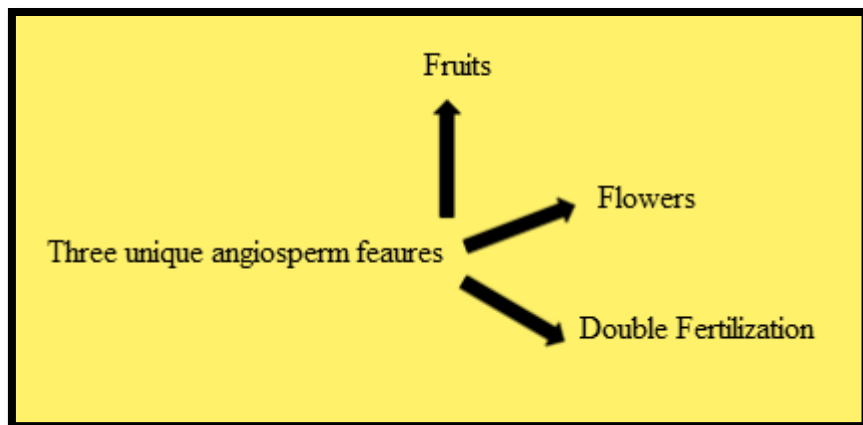
After double fertilization, ovule becomes the seed, and the ovary becomes the fruit. Seeds are multicelled, and will safeguard the embryo. The embryo develops in our plant!

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The endosperm food reserves may be parceled out to the cotyledons.

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Pollination or the transfer of pollen can occur by water or air (wind) transfer, bees, birds, bats, and other insects. All it needs is for the pollen to find a receptive stigma!

Gymnosperms



Plants with naked seeds

★ 1st seed plants ★

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Nonflowering plants... seeds are not enclosed in a chamber as seen in angiosperms, but exposed on modified leaves that form cones.

Conifers are here including Fir, Pine, Cedar, and Spruce (Conifers are the oldest trees in the world).

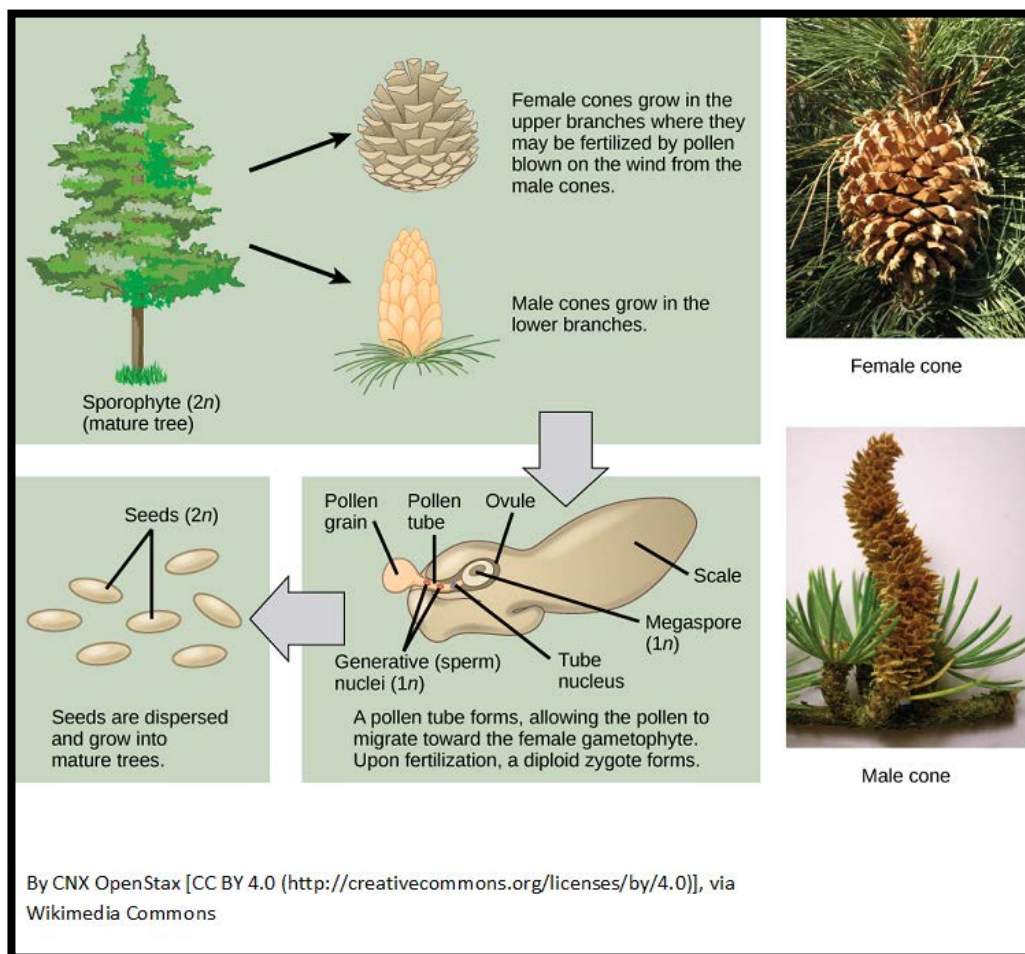
The conifers produce much of the wood for building and paper.

Lesser known gymnosperms are the tropical or subtropical plants called cyads. The reproductive cycle will be similar as in angiosperms, but no double fertilization.

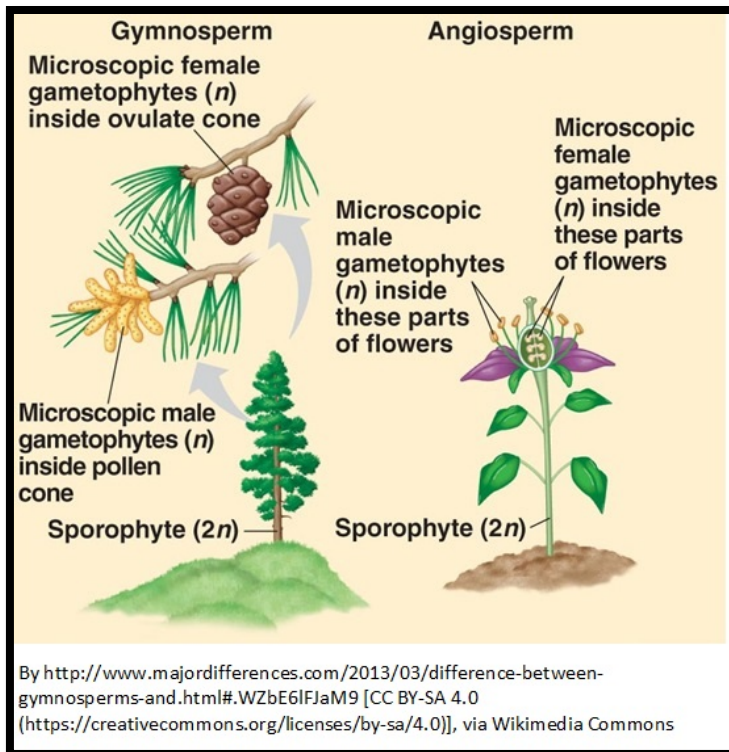
Pollen is shed from the pollen cone and reaches the female gametophyte. The male gametophyte (the pollen) eventually fuses with the egg to make a zygote. The zygote becomes the embryo, and ovule becomes the seed. Sperm are carried to the eggs by pollen tubes, if you recall... hence do not require motility.

Flowering plants make two kinds of spores:

- 1) **Megaspores**... develop in the ovule into female gametophytes
- 2) **Microspores**... develop in the anther into the pollen grains... develop into male gametophytes which give rise to sperm cells.



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Pollination can be...

Self-Pollination:

Pollen grains are transferred from the anther to the stigma of the same flower or at the ovule in the case of a non-flowering plant like a gymnosperm.

Cross-Pollination:

Most flowers do this, we transfer pollen from the anther of a flower of one plant to the stigma of a flower on another plant of the same species.



This will enhance genetic variability!

Angiosperms have animals and insects carry their pollen from plant to plant, while most gymnosperms rely on the wind. Angiosperms have more advanced tissues and diversity than current day gymnosperms, in large part due to more effective pollination. Bees are huge pollinators! They fly from flower to flower transferring pollen grains!

Are there mechanisms to limit or prevent self-fertilization?

Mechanisms exist to ensure genetic variety.

Some plants cannot self-fertilize because different individuals are female or male.

i.e. they contain staminate flowers (lacking the female carpel) or they contain carpellate flowers (lacking the stamen structures). We call plants that are distinctly male or distinctly female **dioecious species**.

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A fragment of a plant (a cutting) occurs and a new individual clone of broken off plant is produced. This is asexual reproduction, unlike the usual sexual mode of reproduction that has been discussed. Often, a number of plants can be grown from the cutting of a single parent plant. The resulting plants are clones.

Plants can also be grafted onto one another in a “modified” vegetative propagation. This could allow desirable characteristics of different plant species into a single plant.

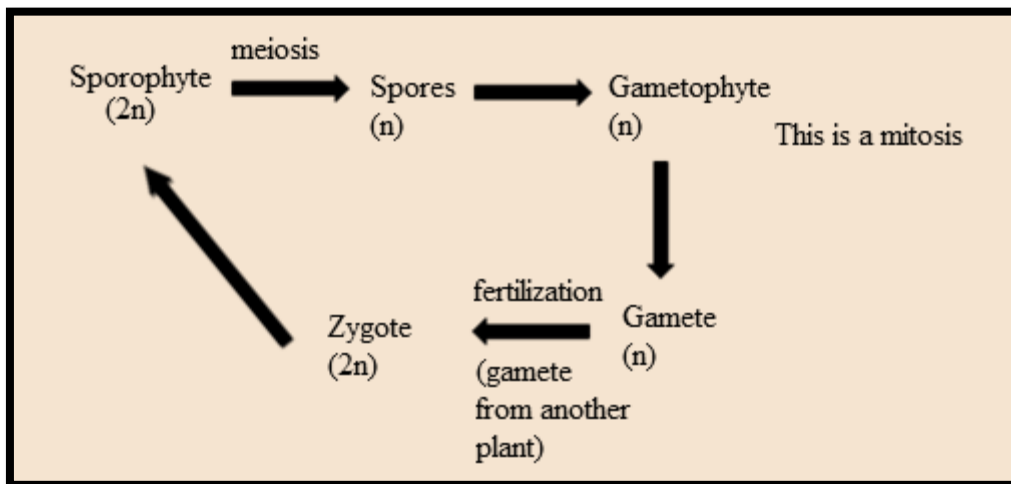
There is a growing debate about genetically modified foods. Science and technology meet culture and politics. Although not a DAT topic that we will explore, the pages written in the Campbell text will be sure to intrigue as well as delight you.

The DAT will not have that many detailed questions on plants, though this is an important topic. This is a good time to take a break before we explore plants II... looking at mosses, ferns, and how plants respond to stimuli.

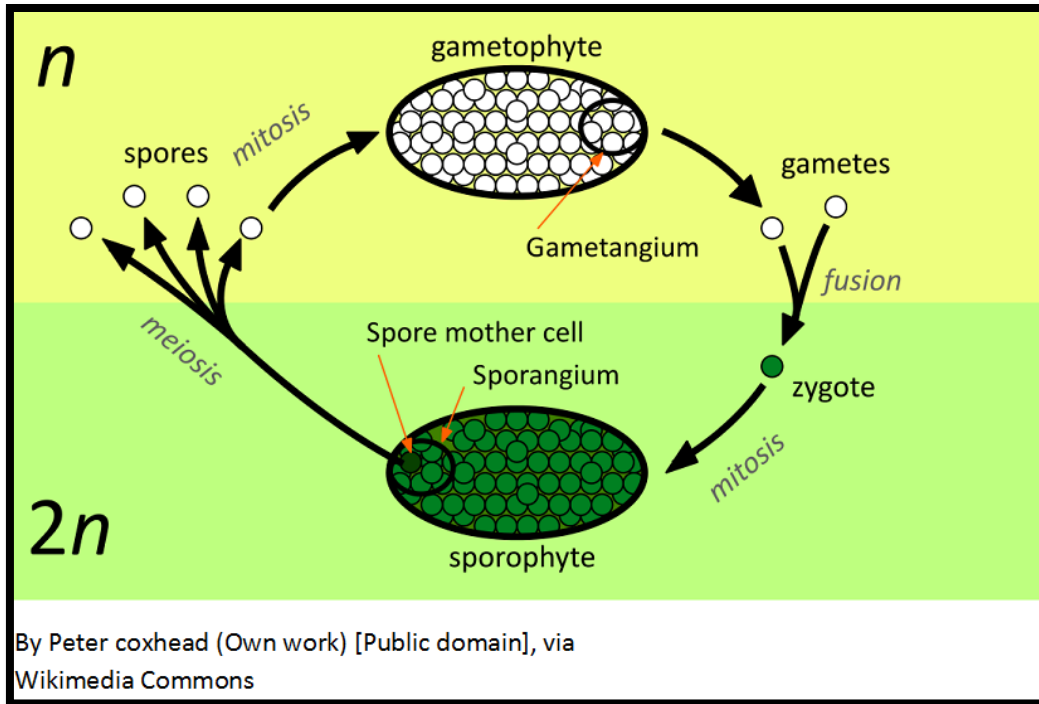
Plants II

Plant life cycles differ from animal life cycles. In plants, meiosis does not directly produce gametes. Recall, that in animals meiosis gave rise to eggs and sperm, the gametes.

In plants... meiosis produces **spores** which are haploid. These spores do not undergo fertilization. These spores divide by mitosis to produce a multicellular haploid plant. Eventually, the haploid plant produces the gametes. Development of haploid spores into haploid bodies necessitates that plants have two body forms: haploid body and diploid body, that alternates with one another. This is called **alternation of generations**. All land plants will display alternation of generations.



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While this general life history description can indeed be applied to all multicellular plants, we do see some variation on this basic scheme. These spores and gametes will be seen in angiosperms (flowering plants) and are protected inside flowers.

The bottom line is simply this... all land plants have this life cycle called alternation of generations which give rise to spores, egg, and sperm.

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Bryophytes



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Non-vascular plants

Oldest of all land plants

Lack xylem and phloem tissue

Moss, liverworts, and hornworts (moss is the most common)

Have waxy cuticles to control H₂O loss

Relatively small; live in moist places

Can be found in Antarctica and even in deserts. Anchored to the ground by **rhizoids** (root-like absorptive structures).

Very sensitive to air pollution

May have evolved from green algae!!

Their life cycles are dominated by **gametophytes**. Unlike vascular land plants, the gametophyte represents the dominant life cycle stage. **(Always an exam favorite question!).**

They need water for the sperm to reach and fertilize the eggs.

Gametes are made in multicellular organs called **gametangia**. Two types:

Archegonia: female gametangia... produces an egg

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Antheridia: male gametangia... produces sperm

The sperm are flagellated and swim to the egg. Fertilization occurs in the Archegonia, where the zygote develops into an embryo.

Ferns

Seedless vascular plants... largest group

Leaves are call fronds

Sori are found on the lower surface of many fern fronds. These are **sporangia** (contains the spores) clusters that are yellow or rust-colored. Like a catapult, they can open and snap shut allowing spores into the air.



The evolution of vascular tissue allows them to grow taller than the bryophytes.

The sporophyte dominates in the fern life cycle. Meiosis will be done in the sporangia, which makes the haploid spores.

Once again, alternation of generations occurs.

★ Ferns are unique plants. They use spores and not seeds. Ferns have **no flowers**.

Thus, moss and ferns are major plant types that have no flowers, no seeds, but reproduce by spores.

This is a major concept, and hopefully you will not forget this.

Interestingly, in March 2017, the oldest plant on Earth was found on ancient rocks from India. The plants are dated to 1.6 billion years old and resembled red algae.

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Plant Hormones

Will control growth and development of plants.

A hormone is released by one cell and targets another.

5 hormones to know:

Auxins:

Promotes stem elongation and fruit development and prevents premature fruit drop.

Some synthetic auxins are used in herbicides

Apical meristems and leaves show most abundance

Cytokines:

Stimulate cell division

Delays leaf aging

Abundant in roots

Gibberellins:

Like the auxins, promotes stem elongation, pollen development, fruit development

Works with the auxins and are involved with the flowering process

Abscisic Acid:

Inhibits plant growth

Inhibits seeds from germinating

Causes stomates to close during times of draught

Ethylene:

A gas that stimulates green fruit into ripening. Found in fruits, plants, seeds, leaves, and even roots. Today, we use it to “accelerate the aging” and allow bananas, melons, etc. to ripen quicker. Also triggers abscisic acid.

What is a tropism? This is a growth response to an environmental factor.

A) Gravitropism: direction growth in response to gravity

B) Phototropism: growth in response to light

C) Thigmotropism: growth in response to physical contact (e.g. a climbing vine grows on your school building)

Factors such as storms, winds, and animals can stress a plant to actually stop its growth. Even shaking a plant (mechanical stress) for a brief period each day could very well inhibit its growth.

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Bottom Line: Be nice to Mr. and Mrs. Plant!!

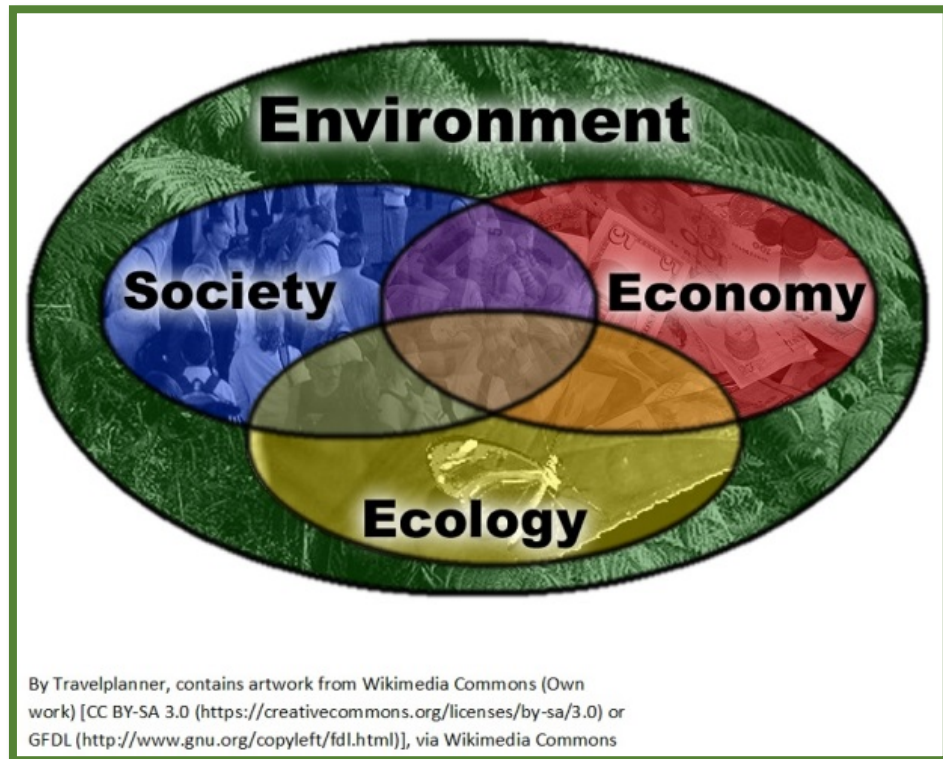
Many plants, like animals, have **circadian rhythms**. e.g. A plant kept in the dark a few days will fold its leaves as if it was sleeping.

Photoperiodism: a biological response to a change in daylight length and darkness in a 24-hour day.

The basis is a blue-green pigment called **phytochrome**, which mostly absorbs red light. This serves as switching mechanism which can control the activation and inactivation of plant hormones. It is like an “alarm button” which can switch mechanisms for growth and inhibition in a timely fashion. Studies are still being done on these receptor/pigments.

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Ecology



The study of the interaction between organisms and with their physical environment.

The DAT asks a surprising number of questions here, so we must know what we are doing.

Let us review a few different **definitions:**

A group of individuals of the same species living in an area is a **population**. They have the ability to interact and interbreed with each other.

Populations are **variable** in time. For example, bird populations change in the summer and the winter. Populations of plants even change; some are dormant for a time, then bloom.

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All populations face limits to growth. Growth cannot be continuously increasing. There will be:

- 1) Competition for resources
- 2) Predators
- 3) Disease



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All of these factors control population growth.

The place where a population lives is called the **habitat**, it is the physical area. Every habitat is characterized by a particular range of temperature, humidity, soil, competitors, predators, etc.

The **niche** of a population or species is its functional role in the ecosystem.

Think of the niche as the organism's profession and the habitat as the address. For example, one day you are a great oral surgeon with an office at 123 Main Street. Your niche is an oral surgeon, and your habitat is 123 Main Street.

An **ecosystem** represents all the organisms present in a particular area and their physical environment. Thus, an ecosystem is composed of biotic and abiotic components. The ecosystem's structure is determined by the biotic and abiotic components making it up.

A tropical rain forest is an ecosystem that possesses the greatest diversity of plant and animal life.

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Coral reefs are ecosystems that are called the “ocean rainforests” because they teem with so much life.



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As you can see, these ecosystems contain not only living animals, insects, and plants, but things that are abiotic (not living) such as soil wind, sunlight, etc.

A **community** represents a group of populations that are comprised of different species in a given area. For example, let's consider a woodland community. In this community we might find, animals, plants, fungi, and bacteria.

One way to tell one community from the next is to look for a **dominant species**. This represents that species that exerts control over the community. A dominant specie can be an animal or even a plant.

Dominant species usually:

- a) Possess greater biomass
- b) Found in greater numbers

The key to this community concept can be summed up in one word: **diversity**.

The greater the specie number and the more evenly the individuals are distributed, the greater will be the species diversity.

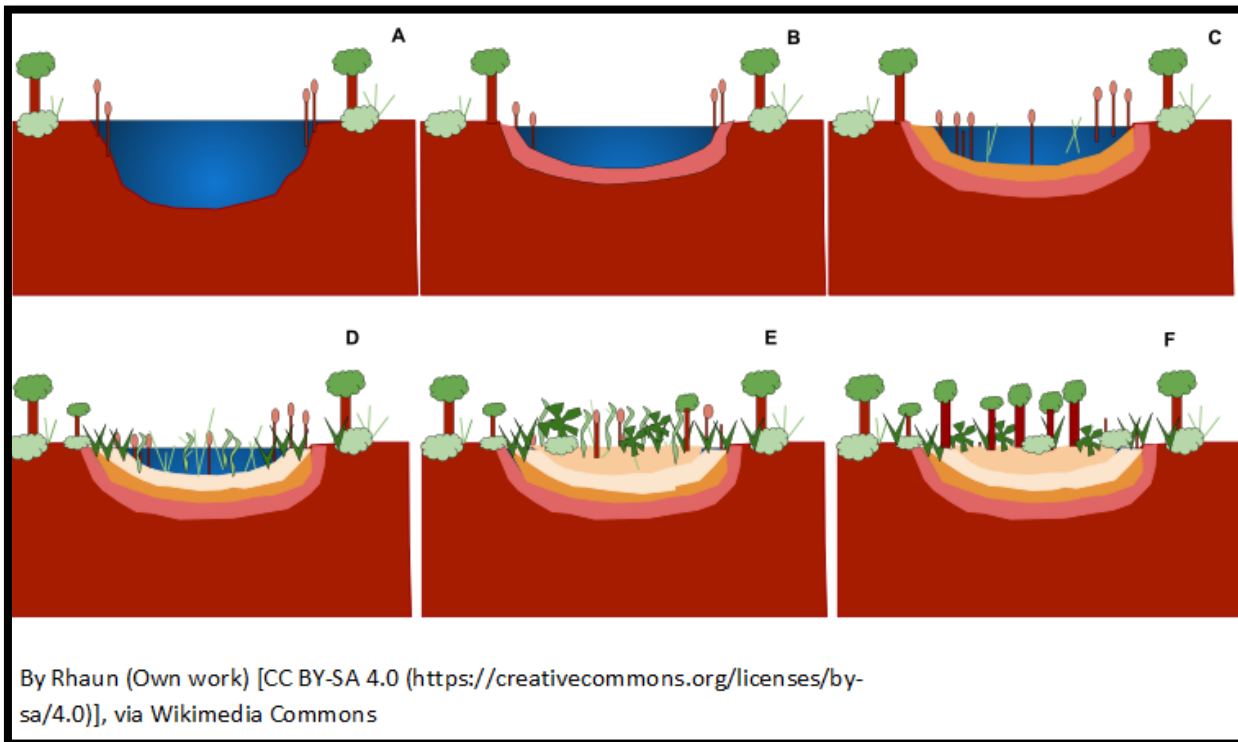
What is a climax community?

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This is a stable community in which populations of animals or plants remain in equilibrium until destroyed by an event such as fire or human interference.

The process by which a climax community is achieved is called **succession**.

Succession is a progressive series of changes that ultimately give rise to a climax community. For example, a pond becomes a meadow, a field becomes a forest. As vegetation changes in a community so do the animals!



There are two types of succession:

- 1) Primary Succession
- 2) Secondary Succession

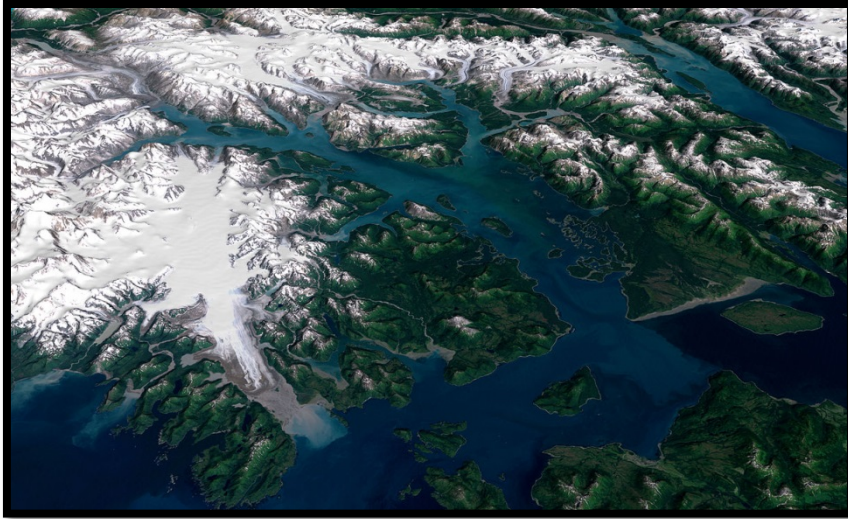
The DAT loves these terms- know the difference!

Primary Succession

Occurs when the terrain was without life, or almost so. The soil has not formed.

- 1) A new volcanic island
- 2) Lava flows
- 3) Glacier retreats
- 4) Sand dunes

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Pioneer species such as lichens and moss usually are the first to colonize the area

Takes a long time!! How long? Hundreds or even thousands of years.

Interestingly, the pioneer organisms set the stage for other organisms and commonly set up their own demise!!

Secondary Succession

Series of community changes occur in disturbed areas that have not been totally stripped of their vegetation or soil.

An existing community has been cleared out by a disturbance such as a fire.

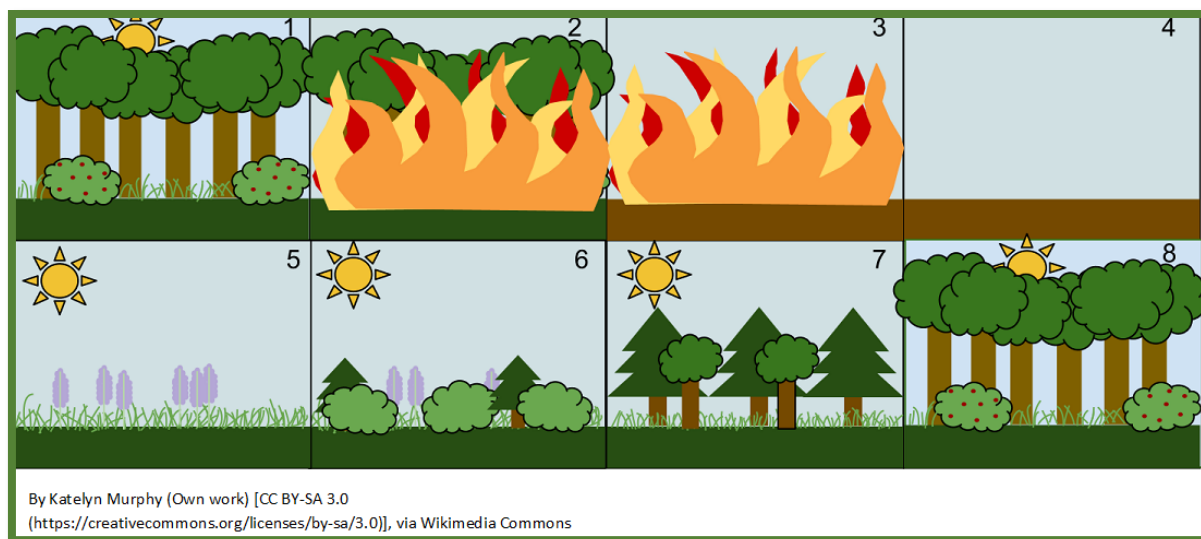
The process is faster than primary succession because soil already exists.

Eventually, we see a gradual return of a climax community to equilibrium following the disturbance.

Besides fire, which is the most common example of secondary succession, let's do another example.

A tall tree crashes to the ground and creates an opening in the canopy of the forest. This allows sunlight and rain to now reach the floor of the forest with full intensity. New plants might begin to appear in this area, along with a bunch of micro-organisms colonizing the dead tree trunk.

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Hopefully, you can see the differences between primary and secondary succession.

Guess what the strongest agent that disrupts the environment would be? **Humans!** Humans have the greatest impact of all. Cutting down trees, polluting the air, ocean trawling, destroying the sea floor, etc. All have a huge negative impact.

Consider the ozone layer... O₃.

This layer protects us from the harmful and damaging effects of ultraviolet radiation. This layer is located in the stratosphere. Since 1975 this layer is becoming thinner. Why?

One answer is the breakdown of chlorofluorocarbons used in manufacturing. The reactions with O₃ destroy the layer. The thinning of the O₃ layer means more UV radiation reaches us on Earth. This can cause pathologies such as cataracts in the eyes, and skin cancers. Plants and crops also are affected in a negative way. The increased radiation damages the DNA. This O₃ layer, which is about 15 miles above Earth absorbs over 97% of the sun's UV light, and is in grave danger of getting thinner.

According to the U.S. Environmental Protective Agency, 1 atom of Cl₂ can destroy more than 100,000 O₃ molecules in a radical chain reaction type mechanism.

Early Earth was a **reducing atmosphere** that contained CH₄, NH₃, CO₂, H₂S, SO₂, and water vapor, but **no oxygen**. Radiation from the sun caused H₂O molecules to split apart. There was no O₃ layer, thus radiation was able to have this enormous impact. When H₂O was split, H₂ and O₂ gas resulted. H₂ is light, and was able to escape in outer space, O₂ remained.

The cyanobacteria also helped. This bacteria carried out photosynthesis and more O₂ was produced. The cyanobacteria are simple prokaryotes, but they made a huge impact on changing our atmosphere.

Chapter 37- Ecology



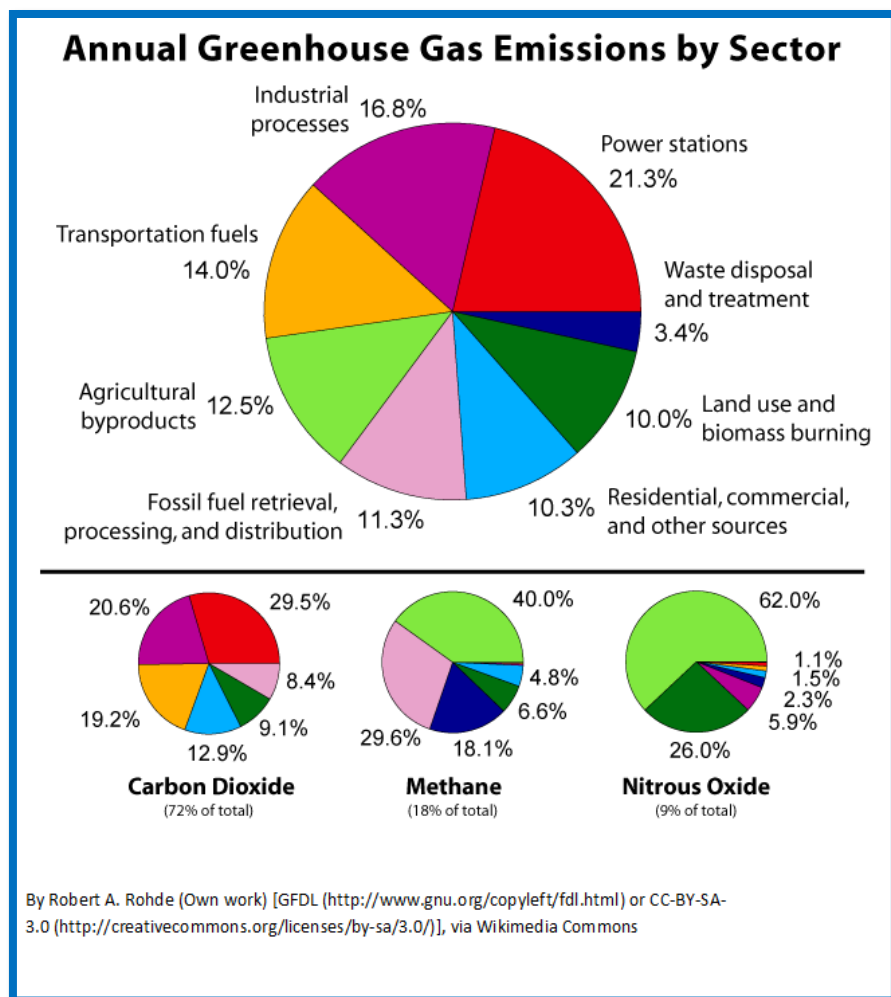
What is a greenhouse gas?

This is a gas in an atmosphere that traps heat. Some greenhouse gases include:

- a) CH_4
- b) N_2O
- c) Hydrofluorocarbons
- d) Chlorofluorocarbons
- e) CO_2
- f) H_2O vapor

These gases act as a blanket and make our planet warmer. Aside from water vapor, most of these gases take years to leave the atmosphere.

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Bottom Line: As we increase the amount of these gases we make the planet warmer, thus we call this global warming. There is much to read on this area. **I think it would give you great practice for the DAT reading section if you simply Google the term global warming and do some reading.**

What is continental drift?

There was a theory that the continents had originally began as a giant landmass or “supercontinent” before breaking apart and drifting to locations where they now reside. This supercontinent was named Pangaea and was thought to originate about 250 million years ago.

This theory helped to explain such things as how fossils in West Africa were the same as those found in South America. The Appalachian Mountains in the United States fit together with the Caledonian Mountains of Scotland.

Evidence for continent movement on what is called tectonic plates, are now extensive. These plates consist of churning currents of molten lava, and can move apart, move sideways, etc. When plates collide, the crust crumples and buckles into mountain ranges.

California has tectonic plates that move relatively fast, thus the area is prone to many earthquakes.

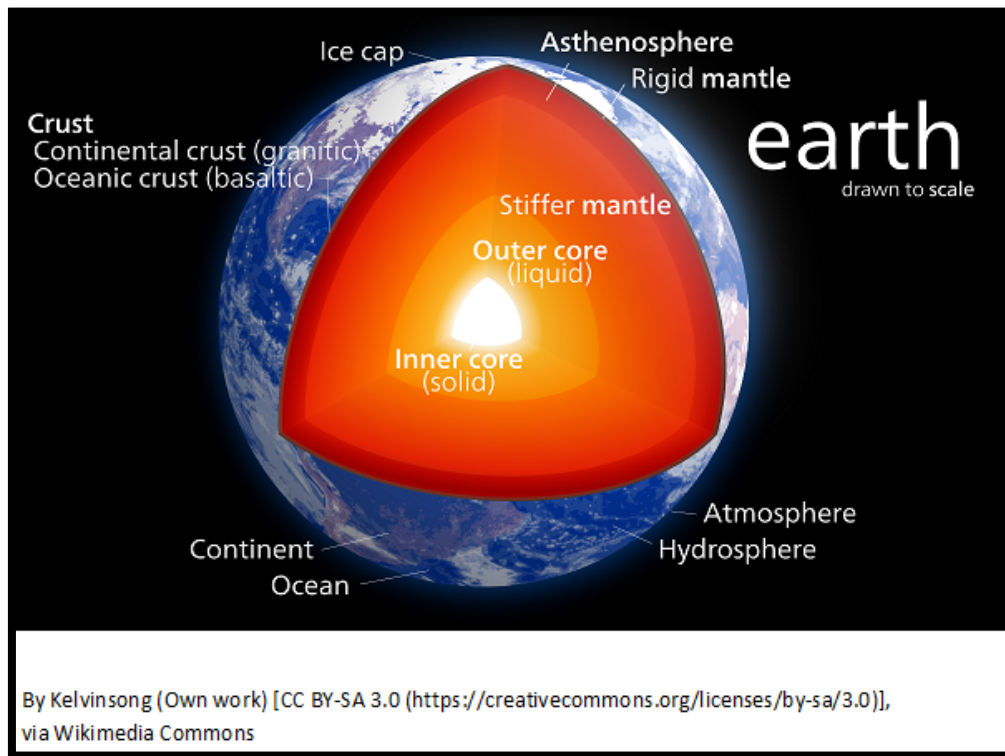
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The **mantle** of the Earth encloses the hot core rich in Fe and Ni. This mantle layer is between the crust and the outer core. It is about 1800 miles!!

The Earth's crust consists of 47% oxygen and 28% silicon.

For the DAT... I advise you to remember two things:

- 1) Air we breathe is mostly N_2
- 2) Earth's crust is mostly O_2



Lakes and ponds are often classified by their nutrient status.

- Oligotrophic:** nutrient poor, but O_2 rich; low productivity of phytoplankton; deep lakes- water is blue or green
- Eutrophic:** nutrient rich, lower O_2 content; shallow areas; high productivity of phytoplankton; water is green-yellow or even brown-green

A lake is an example of a freshwater biome. Biomes are large areas of our Earth which are characterized by the climax community type that it supports.

Marsh: a wet grassland

Swamp: a wooded wetland

Chapter 37- Ecology

Populations display certain characteristics:

- a) Size: number of individuals
- b) Density: number of individuals per unit area of volume
- c) Distribution: pattern of dispersal through its habitat
- d) Age structure: pre-reproductive, reproductive, or post-reproductive classifications

Populations can **randomly disperse**. For example, trees on the forest floor or invertebrates can be randomly dispersed in a forest. The habitat plays no role in determining the location of individuals.

Populations can exhibit **clumped dispersion**. For example, animals from social groups such as schools of fish. This clumping often provides defense against predators, more efficient food foraging, and even more possibilities to find a mate. This is most common! Elk and caribou live in herds. Humans in the USA illustrate clumped dispersion!

Populations can exhibit **uniform dispersion**. Individuals tend to be evenly spaced.

★ Whenever a population shows uniform dispersion this suggests a competition among members. Animals that defend their area tend to be uniformly spaced because they divide the area between them. Some plants which are older often secrete toxins that keep other plants away.

Many factors can affect sustainable population size. (**Common DAT type problem!!**) These factors include:

- 1) Predation
- 2) Competition
- 3) Available resources
- 4) Pollution
- 5) Disease

What is carrying capacity?

This is the number of individuals that can be sustained indefinitely by the resources in a given area. Births are balanced by deaths.

Carrying capacity varies from one year to the next. In times of plenty, a population may increase in size, while in times of famine, a population may decrease in size.

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Population growth rate depends on:

- 1) Birth rate
- 2) Death rate
- 3) Rates of immigration and emigration

Population Growth Regulation

What happens if the carrying capacity is exceeded?

Density-dependent mechanisms will:

- a) Decrease the birth rate
Or
- b) Increase the death rate

If the population falls below the carrying capacity density-dependent mechanisms will:

- a) Increase the birth rate
Or
- b) Decrease the death rate

★ When a population grows its density increases and so does competition for resources, predation, wastes, parasitism, and diseases. These are density-dependent factors.

Clearly you can see when a host population gets too large, members face a higher risk of dying. Predators are lurking, pathogens, and parasites await!

The Bubonic plague killed over 20 million people in Europe in the Middle Ages. Humans lived in crowded areas, sanitation was poor to non-existent, and rats were abundant. The bacterial agent lives in the rodents. Clearly, the carrying capacity was exceeded. When a host population becomes increasingly dense their members face a larger risk for disease.

What are density-independent factors?

These factors do not depend on the population density or size.

Density-independent controls include:

- a) Fires
- b) Earthquakes
- c) Snowstorms
- d) Floods

A freak storm, for example, may wipe out an entire population. If you used an insecticide in your yard, you may kill most insects, mice, and even bird populations regardless of how dense their populations are.

Currently, humans have what is called **exponential growth**.

Chapter 37- Ecology

There are many fancy formulas that ecologists work with and various curves. **However, for the DAT exam here is the bottom line:**

Populations grow exponentially when: the birth rate remains slight above the death rate, and both rates are constant. Immigration and emigration are equal too.

Bacteria also exhibit exponential growth.

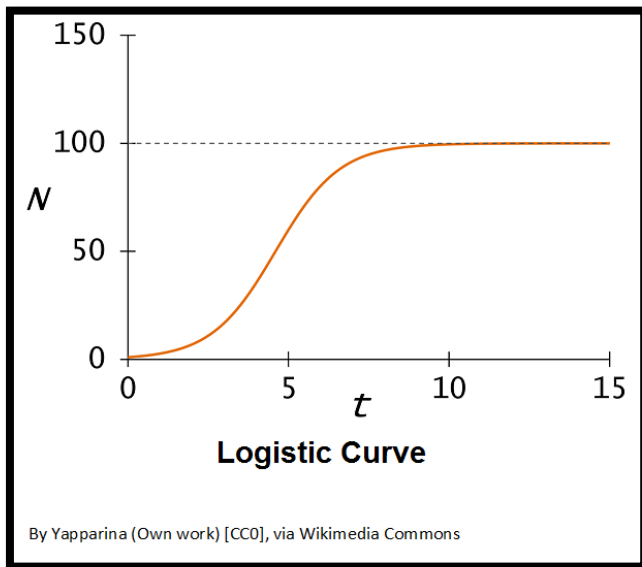
It is obvious that decreasing human birth rates would be most helpful to solving the world's environmental problems.

What is the logistic growth model?

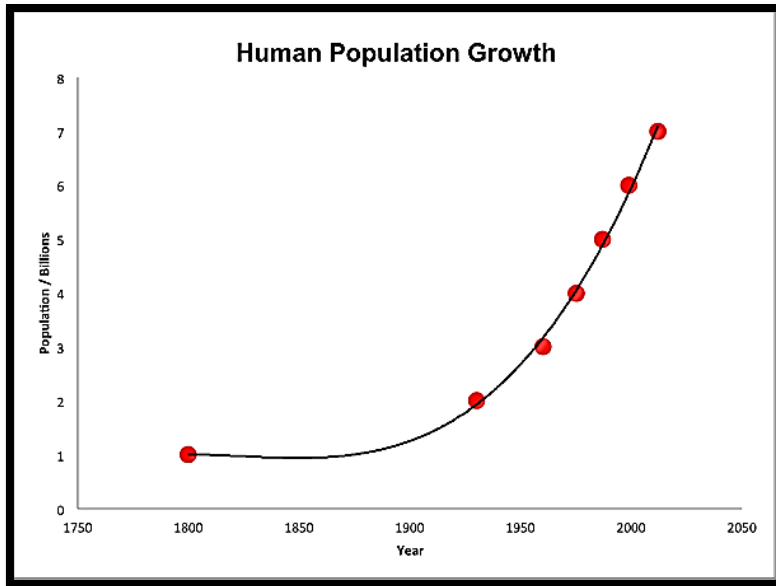
We use the logistic model when a population nears its carrying capacity. The population grows at a slower rate. Logistic growth follows an S-shaped curve.

No population can grow exponentially for very long. When carrying capacity is reached following exponential growth, we see a logistic curve.

The Paramecium Aurelia in a culture medium is a fine example. There is exponential growth in the beginning, but levels as the carrying capacity is reached:



Chapter 37- Ecology



r and k selection

This refers to life history strategies of organisms.

- 1) **r-strategist**: high growth rate with many offspring. There is little parental supervision. Short life spans and waste much energy! (eg. Insects, bacteria, diatoms, rodents, weeds, and corals)
- 2) **k-strategist**: low growth rate with few offspring. There is much parental care. More stable environment is occupied, more stable and energy efficient (eg. Mammals)

Know the difference between these two strategies for the DAT!

★ Logistic growth model: associated with k-selection

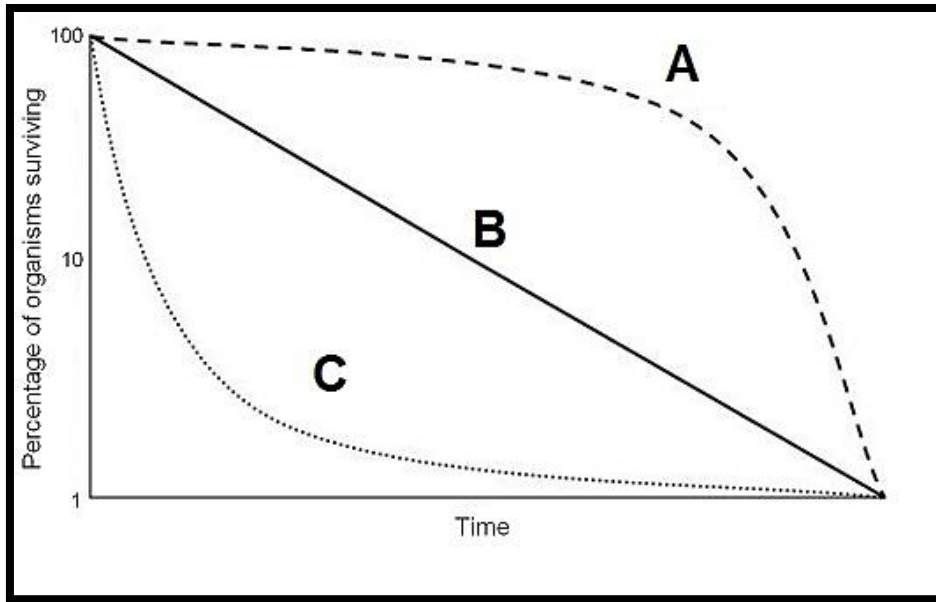
★ Exponential growth model: associated with r-selection

Hopefully, you can see that both selections are part of strategies employed by living organisms.

A **cohort** is a group of same-age individuals in a population.

Let us consider what is called a **survivorship curve**. This curve examines cohorts to see the numbers alive at each age.

Chapter 37- Ecology



A: Humans for example. The curve shows low death rate in the young, and begins to increase with time.

B: Reptiles and rodents for example. The death rate is constant over entire lifespan.

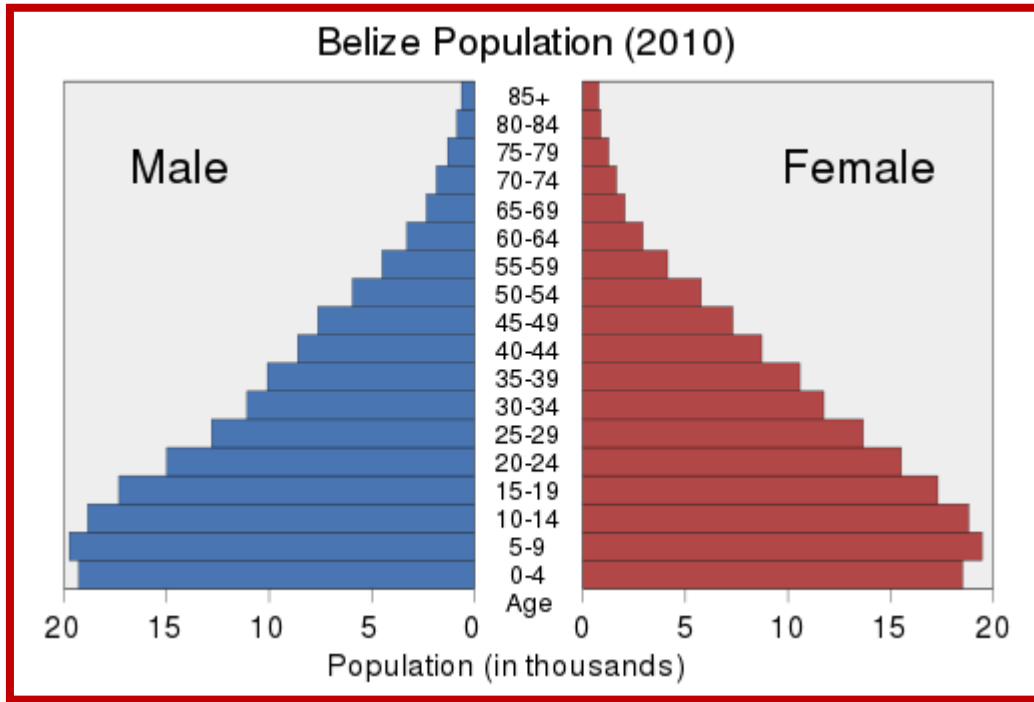
C: Fish and marine invertebrates for example. The curve shows a high death rate for the young, but levels off for the older ones who survived.

Many species fall somewhere between these curves. For instance, a bird follows curves B and C.

For the DAT, understanding the curves should suffice.

Chapter 37- Ecology

A **population pyramid** or **age-structure diagram** can tell a researcher the distribution of females and males by age.



Growth trends are noted here. This is a very young population. This young population will grow up and may sustain the huge amount of growth with their own reproduction.

Demography studies population statistics and how they change over time.

Demographic studies include:

- 1) Sex ratio
- 2) Age structure
- 3) Growth rates
- 4) Mortality and survivorship curves

Has technology increased our carrying capacity?

This is a yes. However, no population can grow forever. Many of us have resources and simply waste them. Others, will perish since they cannot obtain these resources.

Population control will be attained either from:

- 1) Social changes
- 2) War
- 3) Diseases
- 4) Environmental collapse
- 5) Resource limitation

Chapter 38- Ecology and Communities

Ecology and Communities

Recall, that a **community** represents a group of populations of different species living in a close proximity, thus can interact.

The sum total of an organism's interaction with biotic and abiotic resources of its environment is a formal definition of a **niche**.

What is the difference between a fundamental niche and a realized niche?

Know this for the DAT!

A **fundamental niche** is the theoretical niche in which no limiting factors are present. There are no competitors, no disease, no parasites, and no predators.

The niche that is actually occupied by the organism is called the **realized niche**.

If, for example, a predator is present, an organism might avoid the area. The organism will no longer feed in that area. Thus, it's realized niche differs from its fundamental niche.

Communities consist of hundreds of species that interact in bewildering ways.

Symbiosis

Most relationships between two different species in a community are neutral. They neither help nor harm one another.

Let's explore some types of **symbiosis**. A symbiosis is simply a relationship (ecological) between organisms of different species living in a community.

Mutualism: both organisms benefit

e.g. bacteria make vitamin K while living in the human intestine

pollinators and flowering plants



Chapter 38- Ecology and Communities

yucca moth and yucca plant

Commensalism: one organism benefits, but the other organism is neither harmed nor helped

e.g. a bird uses a tree as a roosting site (the tree gets nothing in return, but is not harmed)

A plant, like a fern, uses another for shade

Barnacles living on a whale



By docentjoyce from Los Osos, u.s.a. (Decomposing male Humpback Whale Genitalia) [CC BY 2.0 (<http://creativecommons.org/licenses/by/2.0>)], via Wikimedia Commons

Parasitism: one organism benefits while the other is harmed

e.g. a blood fluke infects a human and causes enlargement of the liver and spleen in addition to other disorders

Chapter 38- Ecology and Communities

Athlete's foot fungus on your feet



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Let's talk about **competition**.

You are applying to dental school... hopefully these notes will help you. You are in a competition with many applicants. **Thus, you better not only know these notes, join my Facebook DAT study group, but do every problem in the DAT Destroyer.**

Competition



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Chapter 38- Ecology and Communities

What happens over time in a community where two species compete for limited resources?

This is a DAT favorite!

What is interspecific competition?

This is a competition when different individuals of a species compete for a resource that limits their growth and survival. A fox and lynx compete with each other for prey is a fine example.

This competition can be especially fierce especially if resources are limited. There are two types of competitive interactions:

- a) **Interference competition:** e.g. corals kill other corals by poisoning them; birds chase other birds away
- b) **Exploitation competition:** both species have equal access to a resource, but one exploits it at a faster rate!! We indirectly harm the other organism's growth, and survival. Obviously, this will not occur if the resources are highly abundant!

It was shown by a scientist named G.G. Gauss of Russia that two species competing for the same limiting resources are unable to coexist.

A slight advantage will cause one to be eliminated. This is known as **competitive exclusion**.

We can restate the principle using the niche idea:

If niches are identical, two species will be unable to coexist permanently in a community. Remember, competition becomes fiercer when resources are in short supply.

How can competition between species end on a good note? In other words, can we have a situation that does not lead to extinction of a species?

Consider what is called **resource partitioning**. Here is an example of resource partitioning.

We have an abandoned field where three plant species exist. Each plant exploits a different part of the soil. Each is able to survive; hence they coexist.

If three lizards, live in a close proximity they would be in competition for resources. There is a possibility that all three lizards could coexist. Again, the idea of resource partitioning.

Lizard A- loves to sit in the shade.

Lizard B- loves to sit in the sun.

Lizard C- loves to climb nice and high

Each lizard essentially occupies a distinct niche, clearly you see their fundamental niche is different from their realized niche. However, this is not always a bad thing, as now our lizard friends can all live!

Chapter 38- Ecology and Communities

Predation



Predation occurs when one species exploits those of a prey species for food. The predator species eats the prey. It can also include plants! e.g.: An animal eats a plant or a lion eats an antelope.

A **parasite** obtains food from the host, which it might kill... maybe not. However, the parasite will live in or live on the host organism for a long time. Parasitism can indeed be considered a form of predation.

★ When predators can keep prey populations from overshooting its carrying capacity a stable coexistence can occur!! This results in a stable relationship.

Predation is often the most important factor that determines population size. It is regarded as a powerful agent of natural selection.

Under normal conditions, predators tend to keep the prey well within the carrying capacity of their environments. Wolves have a hard time killing healthy caribou, but easily kill the sick caribou or caribou that is less fit. Clearly you see, predators help in population control.

Natural selection favors the most efficient predator. Many predators have the following:

- 1) Acute senses
- 2) Teeth or fangs
- 3) Stingers
- 4) Claws
- 5) Fast to move
- 6) Agile
- 7) Thick and strong structures such as beaks and bills

Naturally, the prey just doesn't just sit there and get captured and eaten. They too have **adaptations** that help them survive.

Chapter 38- Ecology and Communities

A variety of defensive adaptations are seen by prey. Let us have a look:

A) Morphological features:

The pill bug and armadillo can roll themselves into a ball! YouTube has a great armadillo clip... you must see this!!

Other animals like the porcupine have structures that protect it from predators.

Many lizards can break off their tails when attacked.

Hermit crabs can carry sea anemones as passengers as the sea anemones protect the crab!!

B) Chemicals:

Some plants fend off predators by using an array of toxins. Some of these compounds are called alkaloids. They include nicotine, caffeine, morphine, cocaine, strychnine, and quinine. These alkaloids have pharmacological effects on both humans and animals.

Some alkaloids inactivate enzymes, others affect DNA repair mechanisms.

Some plants release HCN to ward off insects and other predators.

★ Clearly you see that plants have developed a stunning array of structural as well as chemical defenses to deter against predators.

C) Concealment and Camouflage:

Simply hiding is one of the main ways prey can escape a predator. Running for cover is another way to escape. Concealing themselves beneath tree roots or in hollow logs are commonly seen features.

Protective coloration in lizards, mice, and many arthropods is seen often.



Chapter 38- Ecology and Communities

Bright colors are usually a warning coloration. It is called **aposematic coloration**.

Many poisonous or unpalatable (taste bad) organisms display colors that are bright!!



The granular poison frog looks so nice and pretty, but don't be fooled, the colors are a warning signal to any predators of its toxicity.

Aposematic signals are warning signals, never forget that!!

★ Stripes on a skunk are also an example of aposematic coloration from a mammal!!

Significant protection is bestowed upon some prey species by mimics.

What is a mimic?

A mimic is when a species has the same or similar appearance of another.

Two mimics you need to know for the DAT exam:

- a) Batesian mimicry
- b) Mullerian mimicry

In a **Batesian mimic**, we see **deception**!!

A harmless organism “pretends” that it is dangerous by looking like an organism that is poisonous and dangerous!

For example:

A harmless fly resembles a hornet.

The viceroy butterfly resembles the unpalatable monarch butterfly and avoids being eaten.

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Mullerian mimicry:

Here we see groups of organisms resembling one another. They all have effective obnoxious defenses.



Chapter 38- Ecology and Communities

For example:

Different species of bees and wasps have the same black and yellow stripes.

Surely you see that a predator will learn mighty quick not to mess with either one!!

This Mullerian mimic is very common among bees, hornets, and wasps!!

Many bad-tasting butterflies also demonstrate a Mullerian mimic.

It gets even crazier!! Predators can also play the same game!!

An angelfish uses a natural lure to draw its prey close!! These horrible-looking fish live at the bottom of the sea. The growth from its ear acts as a lure.

Like predators, herbivores such as some tropical fish, sea urchins, and snails can distinguish between toxic and nontoxic plants. Even mammals such as the manatee are herbivores.

Herbivory is when animals eat plants or plant-like organisms.

Remember:

Herbivores eat plants or plant-like organisms

Carnivores eat meat

Omnivores eat meat and plants

Adaptations for herbivory include teeth. Herbivores have flat molars and premolars to grind up plants. To minimize being eaten, many herbivores have eyes on the sides of their heads allowing them a better view of their surroundings.

Don't feel sorry for Mr. Plant. Plants, in addition to chemical toxins, may contain thorns or spines for protection.

Species Diversity

This refers to the variety of organisms which are different that make up the community and includes:

- a) Richness: number of different species
- b) Evenness: the relative specie abundance

Bottom Line: the more species you have, and the more evenly they are distributed, the greater the species diversity. Often, the more species diversity, the more stable the community.

Say we look at a forest and examine two communities of plants:

Community X: 25% plants A, 25% plants B, 25% plants C, and 25% plants D

This would be very heterogenous and this community would be said to have a great specie diversity.

If Community Y had 80% plants A, 15% plants B, and 5% plants C it would not exhibit much heterogeneity or specie diversity.

Chapter 38- Ecology and Communities

Let us examine the feeding relationships between organisms: the **trophic structure**.

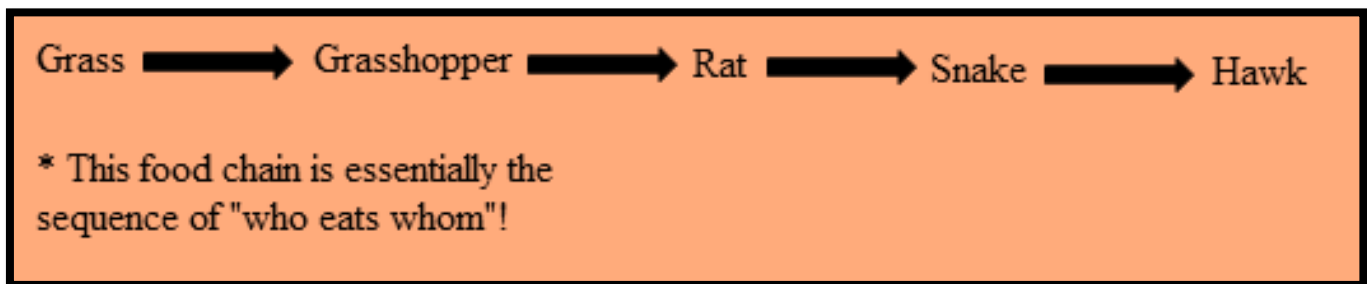
Energy moves in a one-way process through an ecosystem. Organic molecules are broken down, and that energy is harvested by organisms. The sequence of organisms through which this energy moves is called a **food chain**.

A **food web** is two or more food chains linked together.

I will present three sample food chains. They will show:

- 1) A series of living organisms depending on each other for food energy
- 2) How energy flows through a habitat

Grassland Food Chain



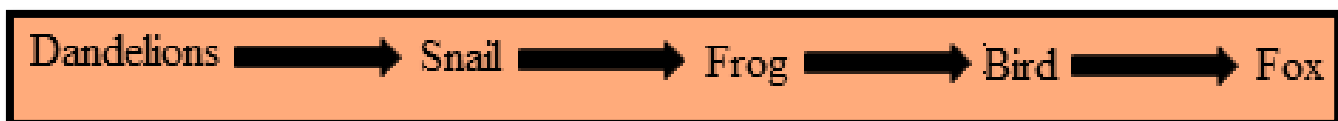
Primary Producer: Grass (autotrophs)

Primary Consumer: Grasshopper

Secondary Consumer: Rat

Tertiary Consumer: Snake

Quaternary Consumer: Hawk



Primary Producer: Dandelions (autotrophs)

Primary Consumer: Snail

Secondary Consumer: Frog

Tertiary Consumer: Bird

Quaternary Consumer: Fox

★ Each food chain will end with a top predator

Chapter 38- Ecology and Communities

Let's do an **aquatic food chain**



Primary producer: Plankton

Primary consumer: Shrimp

Secondary consumer: Herring

Tertiary Consumer: Hope

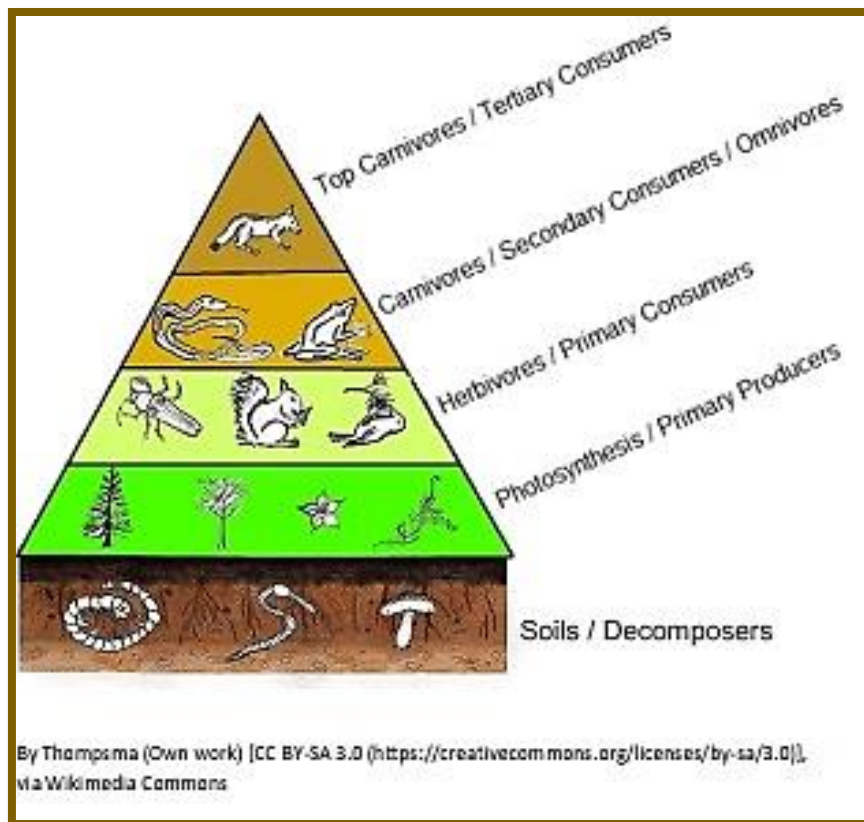
Dead plant and animal tissue is called detritus. Organisms such as soil arthropods and earthworms that ingest the detritus are called detritivores. ★

Decomposers such as bacteria and fungi obtain their energy and nutrients by breaking down dead organic matter. Usually the decomposers are not included in any food chain diagram.

A food chain as I have shown above represents a single path of energy flow in an ecosystem. However, numerous food chains are linked to each other to form complex food webs.

Now, let's take this a step further. Let's bring together all the links in a food web and group them according to their general source of nutrition. We can make what is called an **ecological pyramid** which contains different **trophic** levels.

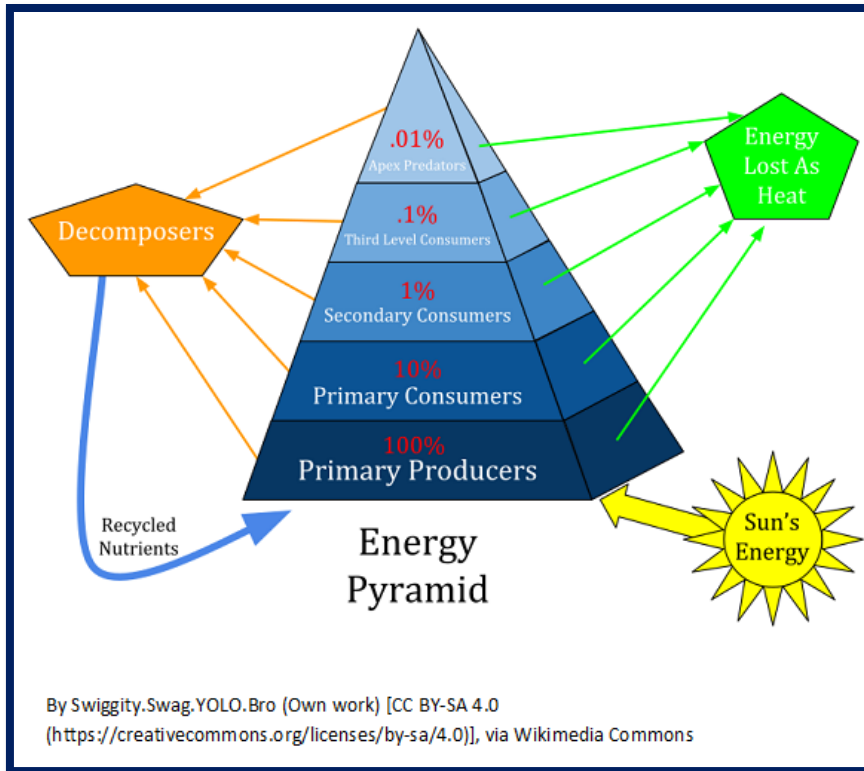
Chapter 38- Ecology and Communities



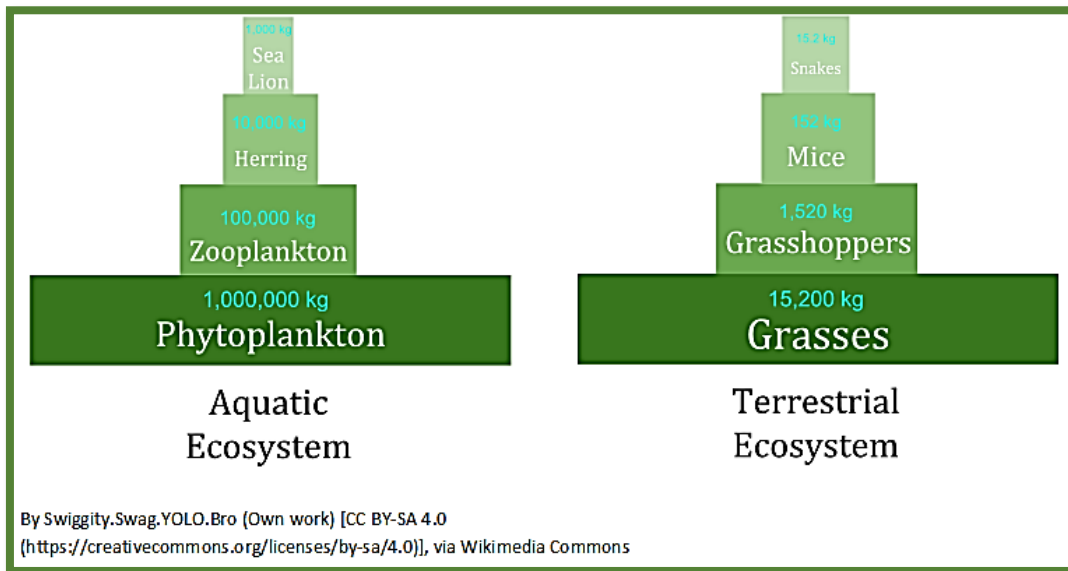
Producers have the most energy and most number of individuals as you go up the pyramid these trends decrease.

Clearly you see different trophic levels represent different **amounts of potential energy**. The producers have the greatest amount of potential energy.

Chapter 38- Ecology and Communities



Let's look at a biomass pyramid... again, I want you to note that as we move up the pyramid we divide by 10.

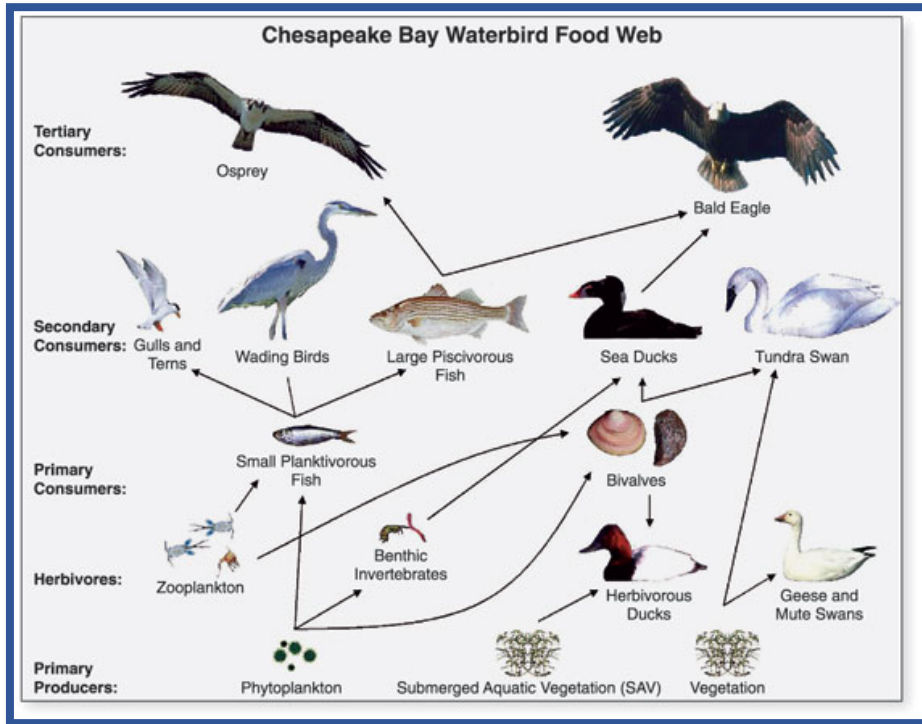


A **keystone species** is a plant or animal that plays a crucial role in the way that the ecosystem functions.

A sea otter kills off many sea urchins that do damage to kelp forests. The sea otter is an example of a keystone specie. Without keystone species, an ecosystem could collapse and cease to exist.

Chapter 38- Ecology and Communities

Since, I love cats so much, let me give one more example. A jaguar is a big cat... a top predator and a keystone specie!! They keep the population of prey in check. Jaguars eat a huge variety of animals. Many of these animals eat plants. If these animals grow too high in abundance, they could deplete plant life. Hopefully you can see the importance of a keystone specie!



Chapter 39- Biogeochemical Cycles

Biogeochemical Cycles

These will describe pathways by which nutrients can circulate through ecosystems. These cycles involve biotic and abiotic components.

These cycles allow us to follow the flow of nutrients through ecosystems.

In many cases, an ecosystem is limited by the availability of inorganic nutrients.

Living organisms require six elements in relatively large amounts... they include:

- 1) Hydrogen
- 2) Carbon
- 3) Nitrogen
- 4) Phosphorous
- 5) Sulfur
- 6) Oxygen

Other elements are in smaller amounts and may include Fe, Co, I, Na, K, B, Br. Many of them are found in salts and minerals. Erosion and weathering can release them into rivers, lakes, oceans, and soil.

Why do we use the term cycle?

The answer is that they may be used over and over again by living systems.

Nutrients can be recycled very quickly, or sometimes it can take years. For example, marine organisms that become incorporated into sedimentary rocks can take millions of years, whereas vegetation on a farm might be replaced with the next growing season.

Elements have different fates, but I will go over with you the cycles that you are likely to be tested on:

Nitrogen Cycle

Nitrogen is found in the amino acids that make up proteins. Plants use two forms of nitrogen:

- 1) NO_3^-
- 2) NH_4^+

N_2 from our atmosphere is unavailable!

N_2 must somehow be able to enter the ecosystem.

About 5-10% comes from the rain. Lightning breaks the N_2 molecules into atoms which can combine with oxygen. When dissolved with water... our rain contains some NO_3^- of which are carried to Earth. 5-10% is the consensus. This is called **atmospheric fixation**.

Now... let's look at another way... this is called **nitrogen fixation**. This ability is found in certain bacteria and archaea.

Chapter 39- Biogeochemical Cycles

Nitrogen fixation requires ATP as well as enzymes.

Where do these bacteria live?

- 1) Some live free in the soil
- 2) Some live in the root nodules of legumes (soybeans, peanuts)
- 3) Some live with organisms (i.e. termites)

Nitrogen fixation gives NH_3 ... which then becomes NH_4^+ which is used by the plant!

However, a great deal of this NH_4^+ is used by aerobic bacteria for energy, which converts (oxidizes) NH_3 into NO_2^- and NO_3^- .

The plant loves NO_3^- and can use this NO_3^- to make amino acids and proteins.

Clearly you see, bacteria are small in size, but mighty in number!

Plants are the only nitrogen source for animals, which feed on them.

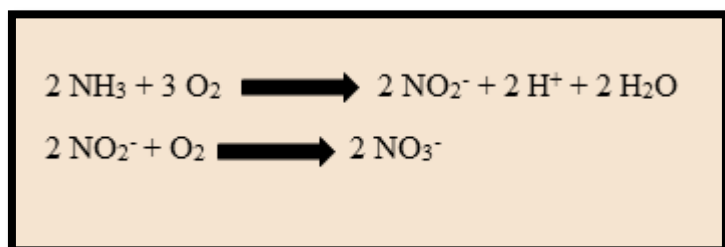
Some NO_3^- , however is converted back to N_2 and returned to the atmosphere. This is called **denitrification**. This denitrification process is done by denitrifying bacteria. These denitrification bacteria live in the anaerobic mud of lakes, bogs, estuaries, and on the sea floor.

Obviously, denitrification lowers soil fertility and decreases agricultural productivity. Denitrification bacteria includes species such as pseudomonas and bacillus.

★ This is done under **anaerobic conditions** (always a trick question- see my question in DAT Destroyer).

Without denitrification, our supply of N_2 would accumulate in the oceans and life would end.

Decomposers also get into the act. Certain soil bacteria and fungi decompose dead organic materials and release excess nitrogen as NH_3 or NH_4^+ . This is called **ammonification**... now our bacteria friends can do the following:

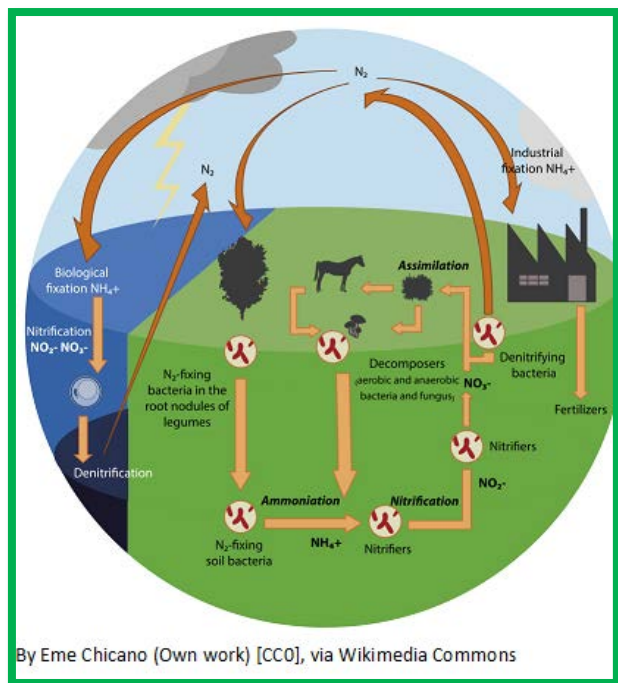


I hope you can see this. I just want you to understand the concept, not memorize these silly reactions. NO_3^- is made available to the plants by yet another source!

I hope you can see that the nitrogen cycle is complex, but understandable for what we need for the DAT.

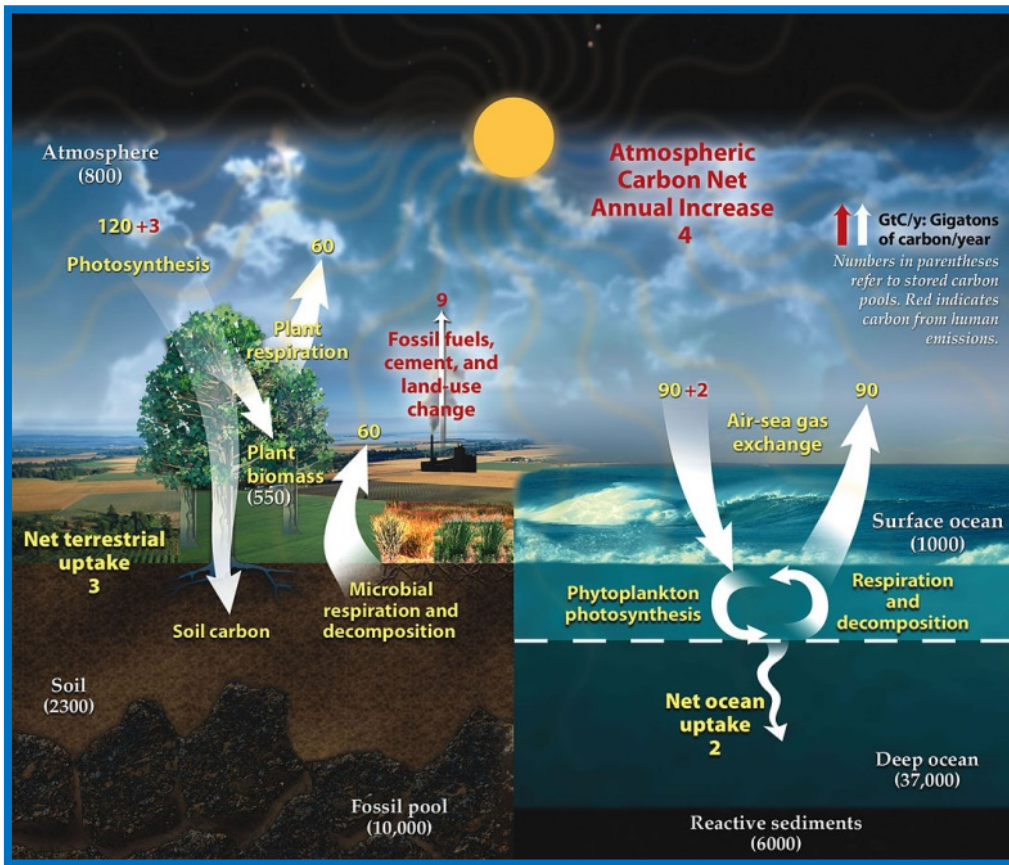
Chapter 39- Biogeochemical Cycles

Actions such as fertilizers play a role, but microbial actions are the most important in this nitrogen cycle.



Chapter 39- Biogeochemical Cycles

Carbon Cycle



Here we deal with CO₂ balance.

CO₂ comes from cellular respiration, fossil fuel burning, volcanic eruptions, and bacterial decomposers.

Photosynthesis uses this CO₂ and makes O₂. This cycle is an exchange between two main “players”:

- 1) Atmosphere
- 2) Ocean- ★ main carbon reservoir!! Oceans contain almost ¾ of the carbon, mainly in the form of HCO₃⁻ and CO₃⁻ and a small percentage in dead organic matter and phytoplankton.

In Aquatic Food Webs: C becomes incorporated into things like shells

In Deep Oceans: dead, shelled organisms sink to the bottom and become buried in sediments.

Know this !You might just one day thank me 😊

Chapter 39- Biogeochemical Cycles

The burning of fossil fuels have indeed added addition CO_2 at an alarming rate. CO_2 absorbs heat from the sun. This “ CO_2 blanket” will likely dramatically increase temperatures here on Earth and the results will not be good.

The Phosphorus Cycle

Recall that P was found in ATP, DNA, RNA, and cell membranes. P is also needed by animals for shells, bones, and teeth. Unlike the cycles of nitrogen and carbon, phosphorous does not present itself as a gas, but rather a solid. Thus, we have what is called a sedimentary cycle.

Sedimentary rocks of marine origin are where we find the largest phosphorous accumulations. Phosphorus does not enter the atmosphere, rather it remains on land in rocks and soil minerals.

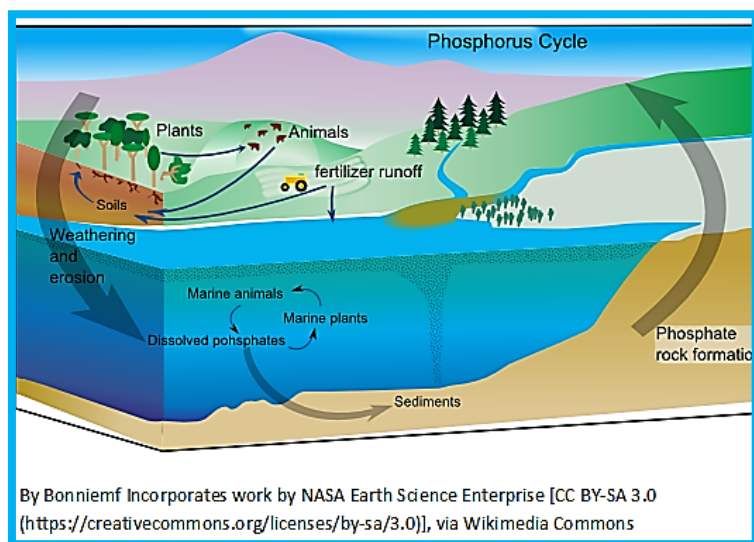
Points to know:

- 1) Weathering over time causes rocks to release some phosphorus in the form of PO_4^{3-} , which is then parceled in soil and water.
- 2) Plants take up some soil PO_4^{3-} which are then eaten and taken up by animals. (When a plant or animal dies, PO_4^{3-} is returned to soil).
- 3) Within the soil, bacteria can allow phosphorus to be made available to plants, although this is a very small contribution.

Humans can alter the phosphorus cycle in many ways. Destroying tropical rain forests, nutrients stored in rocks and plants are destroyed.

Crops can't absorb all the fertilizer used, thus excess fertilizer causes phosphates to end up in our waterways. This increase causes more micro-organisms to live and depletes O_2 . Many fish and marine life parish. Laundry detergents at a time were very high in phosphorus, but most no longer include phosphorus as an ingredient.

In **eutrophication**, bacteria and algae experience an intense exponential growth which uses up all the available O_2 . This kills off many species in the marine ecosystem.



Chapter 39- Biogeochemical Cycles

Water Cycle

As you all know, water is essential to all living things. Believe it or not, chemists are still puzzled about many of the unusual properties to H_2O .

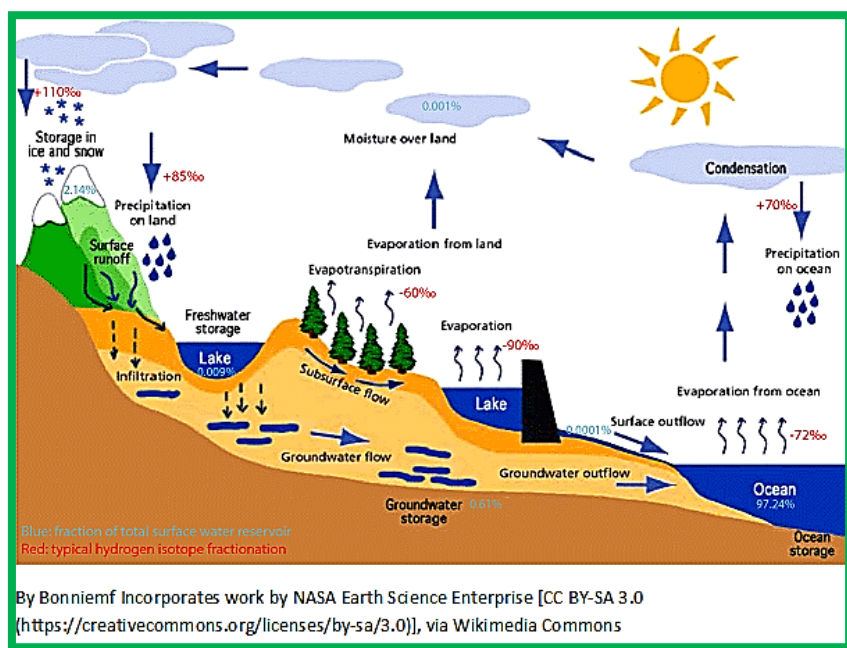
Recall, water has hydrogen bonding between its molecules. Hydrogen bonding gives rise to physical properties to water such as:

- 1) Abnormally high boiling point
- 2) Low vapor pressure
- 3) High surface tension
- 4) Solid phase less dense than liquid phase

Most of this cycle occurs between **ocean and atmosphere** through the processes of **evaporation and precipitation**.

Unlike the other cycles I showed you which all involved some chemical process, most water movement will be done by physical processes during such things as evaporation, transpiration (loss of H_2O in plants), and precipitation.

Yes, H_2O can be made by metabolic processes as well as photosynthesis, but this is a very small percent.



Bottom Line: H_2O evaporates from oceans, it is lifted, it cools and condenses to form the clouds. Moisture is then shuttled around our planet until it returns as rain (precipitation). Once on the ground, some may evaporate, or some may penetrate the surface and become groundwater. This groundwater can go back into rivers, lakes, or oceans.

The water cycle does indeed involve energy changes. **Let's review our general chemistry:**

Chapter 39- Biogeochemical Cycles



This represents melting and evaporating... heat is put in (absorbed) thus the surroundings, namely the environment is cooled.

If a: **Gas** → **Liquid** occurs, this is condensation and is exothermic, hence the surroundings, namely the environment is heated. These heat exchanges influence climate.

Bottom Line:

+ ΔH ... endothermic process... surroundings get cool

- ΔH ... exothermic process... surroundings get warm

DAT favorite question: no need to thank me... your kicking ass is good enough!!

Human Activity

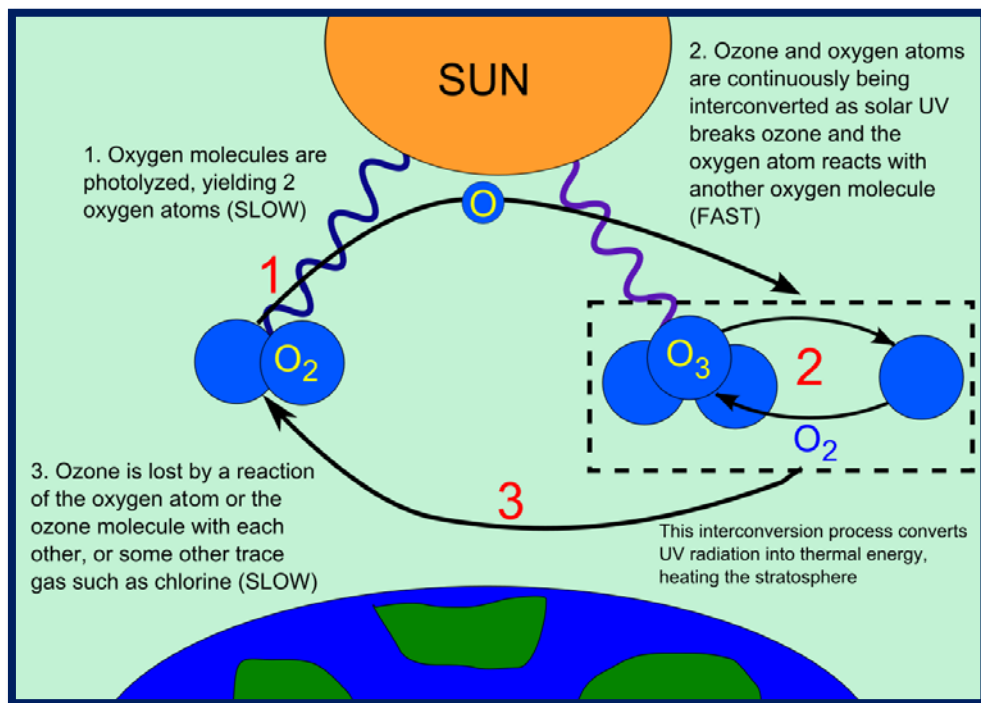
The biggest danger to our biosphere is human activity.

Burning Fossil Fuels: elevates CO_2 levels leading to a greenhouse effect. Warm temperatures can cause sea levels to rise.

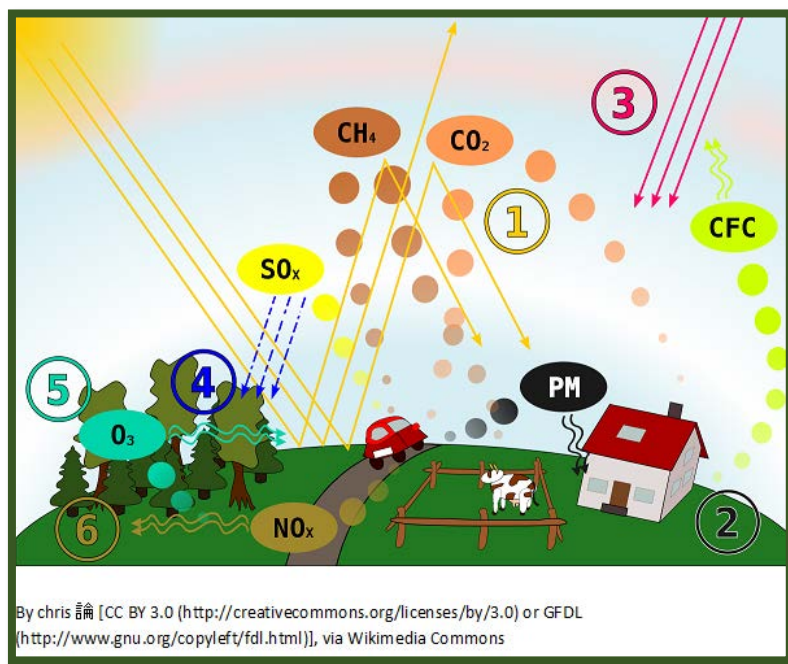


Chapter 39- Biogeochemical Cycles

Depletion of Ozone layer: pollutant such as chlorofluorocarbons damages the ozone layer. Skin cancers, cataracts, and crop damage can result.



Acid Rain: emissions of SO_2 and nitrogen oxides react with H_2O to produce acidic compounds. Electricity, generators, factories, and motor vehicles are the cause. The burning of coal is a large culprit. When acid rain falls to Earth, harmful effects to our soil, lakes, and streams result.



Chapter 39- Biogeochemical Cycles

Deforestation: loss of habitat to millions of species. The world's rain forests could vanish within our lifetime. Many animals cannot survive if it was not for the forest. Removing trees deprives the forest of its canopy. The canopy blocks the sun's rays during the day, and holds heat at night. Temperature swings can occur that will harm animals and plants. Trees also help to absorb greenhouse gases.



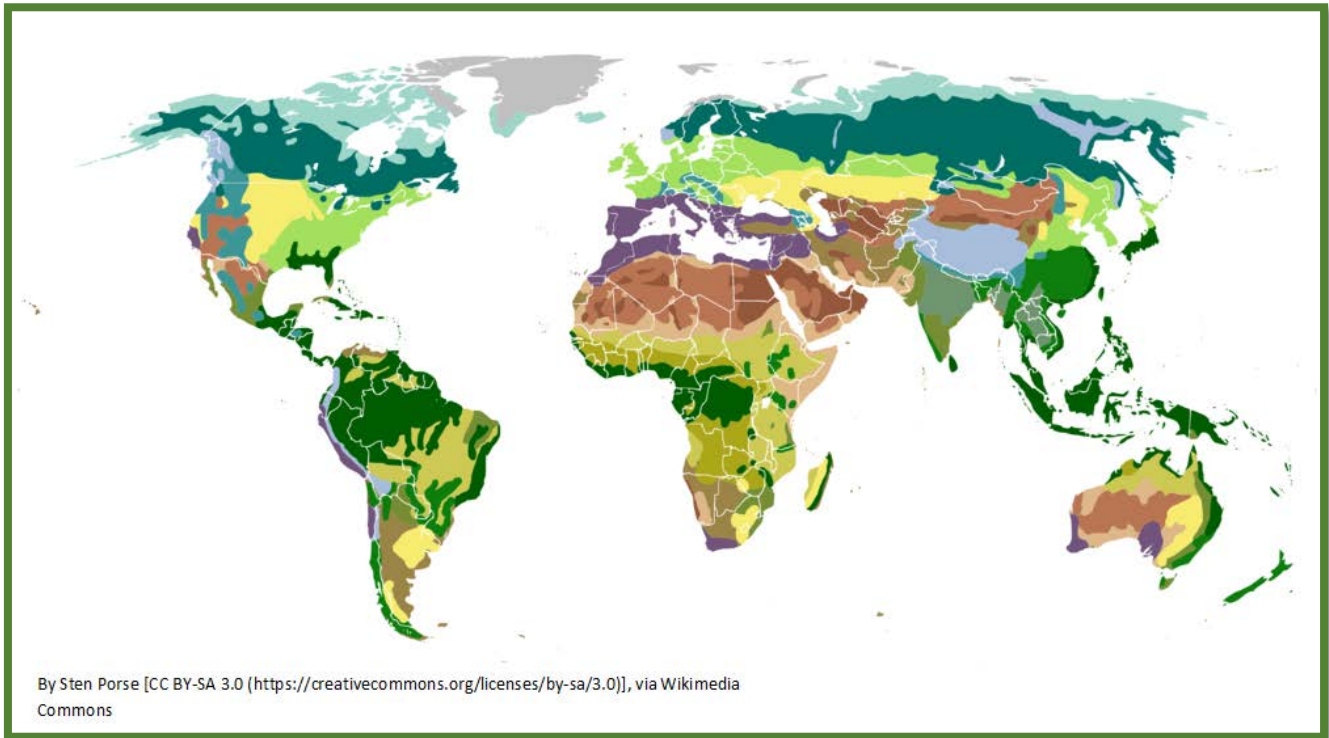
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Pollution from Chemicals: pesticides for example can be ingested by animals. Chemicals high in phosphates stimulate algal blooms which cause eutrophication.

Clearly, you see the need to change our wasteful ways and decrease our carbon imprint on our planet. The survival of our plant depends on all of us.

Chapter 40- Biomes

Biomes



A biome is a large ecological area which contains plants and animals showing adaptation to their environment.

We often define a biome by **abiotic factors** (not living). These factors include:

- 1) Topography (region's physical features such as mountains, and elevation)
- 2) Climate
- 3) Soil
- 4) Vegetation

Let us go through each biome and be **prepared for the questions on the DAT exam.**

Tundra

The coldest of all land biomes

Least bio-diversity capacity

Chapter 40- Biomes

Arctic Tundra:



Located around the North Pole in the Northern hemisphere. Northern Russia, Canada, and part of Scandinavia.

Moss, lichen, grasses, and low-growing shrubs

Very cold

★ Less than 10 inches of rain a year!

Permafrost is seen, soil is permanently frozen, this prevents drainage, thus soil stays waterlogged.

Treeless biome

Oxen, bears, wolves, **artic foxes**, and birds are found here. Fish such as cod and salmon too!

-30°C is common in the winter and 10°C is common in the summer.

Caribou herds can be seen during its annual migration.

This is a fragile biome, since plants and animals must survive extreme cold.

Chapter 40- Biomes

Alpine Tundra:



At high altitudes on mountain tops we find the alpine tundra, think 11,000 feet or more!!

Similar to the arctic tundra but lacks a permafrost or if one is present, it is poorly developed.

Trees cannot grow here, and little vegetation cover. Birds and mountain goats are seen frequently, sheep and elk too.

The Alps, Himalayas, and Scandinavian mountains have Alpine tundra.

Climate becomes colder as you move into higher elevations.

Plants such as grasses and low-woody shrubs dominate the landscape. These plants are subject to high radiation, wind, cold, and snow.

Again, low precipitation, around 10 inches a year.

Chapter 40- Biomes

Taiga or Coniferous Forest



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Largest terrestrial biome (apart from the oceans)

Vegetation dominated by Spruce, Fir, Hemlock, and Pine trees.

Cool summers, cold winters and short growing season of about 4 months.

Also called the **Boreal forest**

Seen in areas such as upstate New York, Alaska, Canada, Russia, Norway, Sweden, Finland, etc.

Many animals like bear, moose, lynx, fox, wolves, deer, hawks, etc. and most have fur to protect them from the cold temperatures.

Sadly, extensive logging by humans may one day cause the disappearance of many Boreal forests.

Forest fires can burn thousands of square miles annually. However, fire does stimulate the regeneration of many plants, it can also recycle such elements as phosphorus. Thus, unlike logging by humans, fire is not all that bad.

Chapter 40- Biomes

The fallen pine needles do not decompose so easily. The mycorrhizal fungi that grow on the roots of the coniferous trees help to decompose them. In return, they provide nutrients for the fungi.

Temperate Deciduous Forest



Found South of the taiga with similar plants!

Relatively high amount of rainfall, 50°F is the average temperature and 50 inches of rain per year

Dominated by trees that lose their leaves each year-★ “deciduous” means falling off or at a certain season!!

Warm moist summers, mild winters

Oak, maple, beech, elm trees- **very fertile soil!**

Season appearance and disappearance of a **canopy!!** ★

Many animals are here including deer, raccoons, porcupines, and foxes. Obviously, all these animals must show an adaptation to the changing seasons. Some of them will even hibernate during the winter, some might even decide to migrate South for the winter.

Many are found in the Eastern United States, Canada, Europe, China, and Japan

The New York City biome is the temperate deciduous forest. **I posted this on the Facebook DAT Destroyer Study Group, I hope you will all join!! Few students knew this answer.**

Other major cities located in this biome besides mine (NYC), include Boston and Toronto, Chicago, even parts of Minnesota like Minneapolis.

Chapter 40- Biomes

Tropical Rain Forest



By Michael Cory from Brooklyn, USA (rain/forest) [CC BY 2.0
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In equatorial regions of Central America, parts of South America, Africa, and Southeast Asia.

Mean daily temperature is the same throughout the year

Rainfall is abundant all year long, 155 inches is not unusual

The highest diversity of plants and animals inhabit this biome. The hot and humid conditions allow for an ideal environment for microorganisms. Millions of unknown insects, arthropods, still exist in this biome!

Tropical rain forests produce 40% of oxygen on Earth- this is a huge percentage!

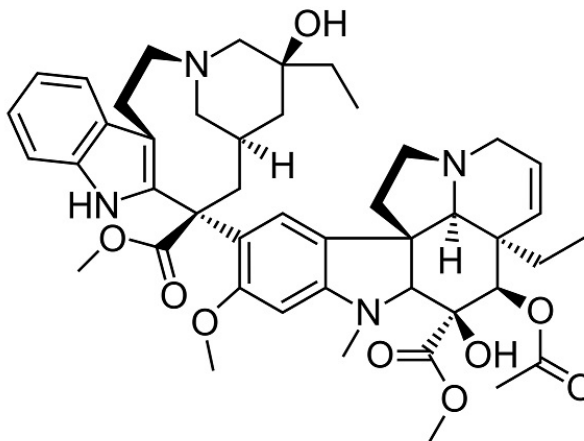
70% of the plants are trees, and many contain molecules with very very elaborate stereochemistry. We can use these elaborate molecules to make drugs. Quinine from the cinchona tree can be used to treat malaria. Other drugs can be used to fight cancers such as leukemia.

Chapter 40- Biomes

Rosy periwinkle is used in treating childhood leukemia. Vincristine and Vinblastine are two drugs we can build using this plant. I do not want you to worry about these names, but I do want you to understand the concept and the huge importance of this biome.



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Look at the enormous complexity and the enormous number of chiral centers. As an organic chemist, I assure you that this would be no easy synthesis. Luckily, Rosy Periwinkle builds mostly all the “framework” and we simply have to do a few molecular interconversions to get the needed chemotherapy drug!

Epiphytes are plants that nourishes itself, but grows on the surface of another plant for support. e.g. orchids.

These epiphytes are often seen in the tropical rain forest.

Highly stratified canopy is seen. The soil is not very fertile, but due to the high temperature net production is very high.

Mycorrhizal associations are common; they allow trees to obtain their nutrients.

The dense canopy permits little light from reaching the forest floor. Few plants can grow, thus allows a person a fairly open path to walk through.

The Amazon basin has the largest, continuous rain forest.

Again, unfortunately the biggest threat to the tropical rain forest is humans.

Desert

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Occur in regions having **less than** 10 inches of rainfall a year

Found at latitudes about 30° North and South or even interior latitudes such as the Gobi Desert.

Can be warm or cold. The North American deserts are hot as is Mexico, but a cold desert includes areas of Antarctica, and Greenland. Only about 5% of North America is desert.

Very dry land

The Sahara Desert is the world's largest hot desert.

Since there is very little water vapor in the air, the nights in the desert are often very cold. A 30°C temperature change is easily seen.

Animals include seed-eating rodents such as the kangaroo rat, lizards, scorpions, etc.

- ★ Recall that a Kangaroo rat had a long loop of Henle. Despite the name, it actually has more in common with a camel. Unlike any other rodent on Earth, it can survive in the desert with virtually no drinking of water!!



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Chapter 40- Biomes

With such a long loop of Henle, this Kangaroo rate produces the most concentrated urine of all mammals, and urinates a few drops each day. Very little water is lost as you can see. The animal eats seeds high in carbohydrates which yield water when metabolized. Their kidneys produce urine that is 5x more concentrated than human urine. Thus, they lose very little water.

Deserts are associated with what is called a **rainshadow**. This is an area having little rainfall because it is sheltered by mountains or hills.

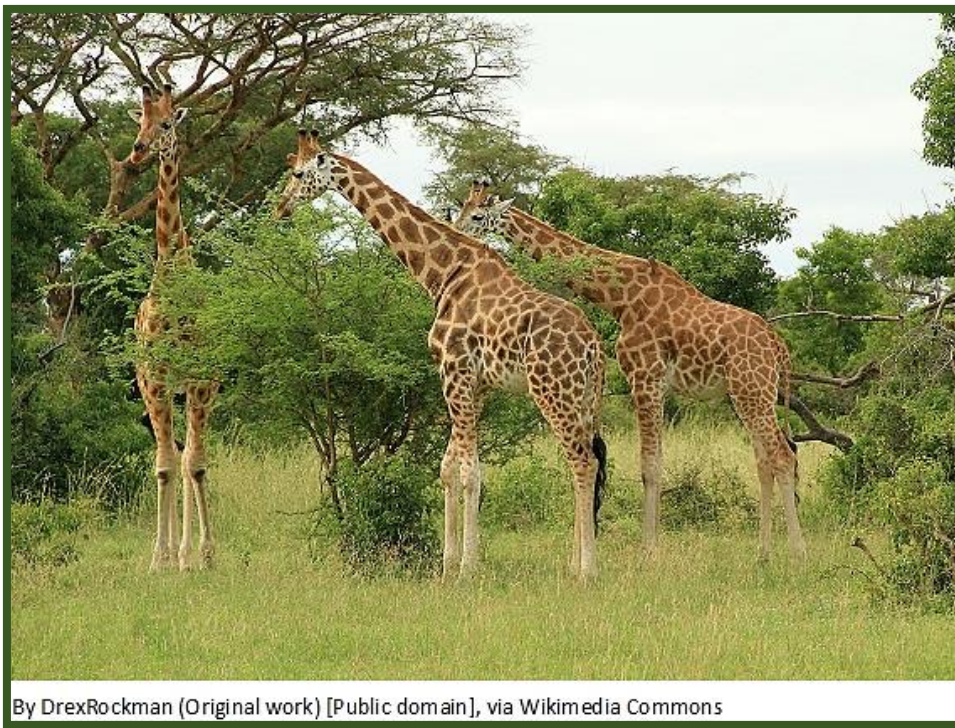
Bottom Line: Rainshadow is a dry area in the desert biome.

Plants include cacti which are succulents (they store water in their tissues), as well as small woody shrubs.

Desert plants need adaptation to things such as heat, water storage, and decreased surface area to their leaves.

★ Clearly, you see that plants as well as animals must have adaptations to their environment if they are to survive. Adaptations are special features that allow plants and animals to survive in a given biome. **This is a very important concept that is sure to appear on your exams.**

Savanna



Found in areas such as Africa, Australia, India, and South America.

Usually warm climate-tropical!

Mostly grasses with a few scattered trees (described often as an area of grassland).

In African Savannas, we find elephants, zebras, horses, and giraffes. The African elephant is the largest land mammal in the world.

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This is a transitional biome- meaning that it is an intermediate between a forest and a desert.

Seasons are defined by the amount of rainfall, thus there is only two seasons:

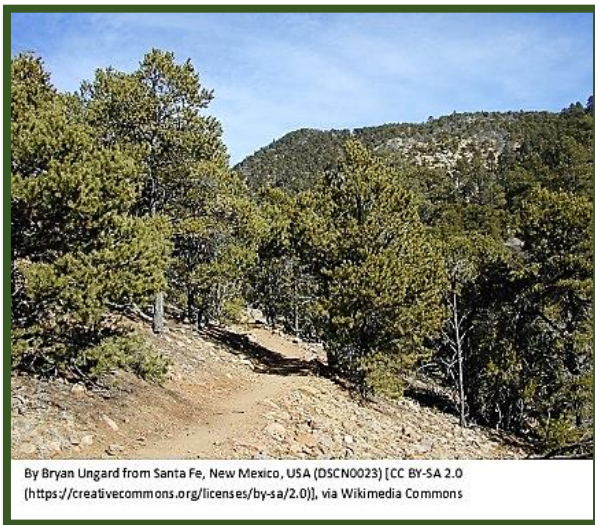
- 1) Wet Season: about six months, sometimes called the “The Monsoon Season”
- 2) Dry Season: no rain for months!

Because of little rain in dry season, seasonal droughts and fires are common. Adaptations need to be made by animals to migrate and for plants to conserve and store water.

The Savanna is the optimal environment for **ungulates**. These are animals with hooves such as elephants, zebras, hippos, and giraffes.

Tropical Savana has been largely disturbed by humans and are rapidly disappearing.

Chaparral



Found in areas such as the West coast of the USA and the West coast of South America. In California, a place like Santa Barbara is a nice example (Chaparral covers 5% of California).

Very hot and dry, most rain comes in the winter. The summer is dry and hot.

Mainly grassland and desert animals such as lizards, rabbits, and coyotes. Many animals are nocturnal (they sleep in the day and play at night!).

Trees and cacti are present

Many types of terrain (i.e. rocky, flat, or mountain slopes are common)

Most plants have small, hard, leaves that hold moisture.

This biome has both forests and grasslands.

15 inches of rain a year and 65°F is about the norm

Chapter 40- Biomes

Many people confuse this biome with the desert, but it receives **more rainfall** than the desert.

Grassland



Large and rolling

The great plains of the USA!! Along with areas of Australia and South Africa

Grasses, herbs, and many flowers with few trees.

Called prairies with many animals and hundreds of bird species

Winters can be -20°F while the summers are over 100°F!!

25 inches of rain a year!

The Savanna is a grassland, but is split up here.

Grasslands have some of the **richest soils** in the world!! These soils are used for farming.

All continents except Antarctica have grasslands.

Some grasslands are flooded seasonally or year-round such as the Florida Everglades.

Some grasslands are located in the Montane Zone, at high altitudes.

Many reptiles, animals, insects, and birds are here.

For example, bison is seen and horses are common.

Some authors classify the American Prairie, African Savannah, and Chaparral under the Grassland biome.

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Definitions:

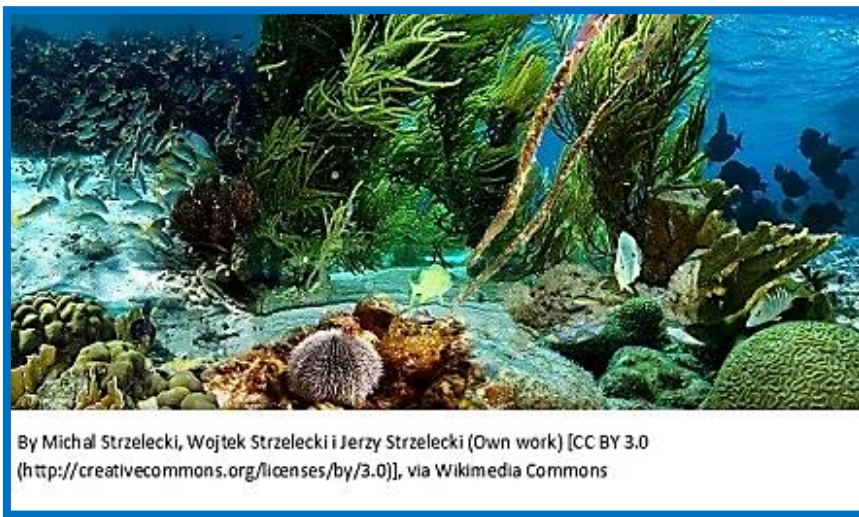
Biotic vs. Abiotic

Biotic: Pertaining to living organisms (includes behaviors and interactions)

Abiotic: Pertaining to non-living organisms (abiotic factors include sunlight, soil, temperature, and water)

Habitat Selection: this is a choice made by an organism to where it will choose to live. This might influence survival and fitness of individuals. For example, in Bermuda dense bird populations are found mainly in areas of scrub plants.

Marine Biomes



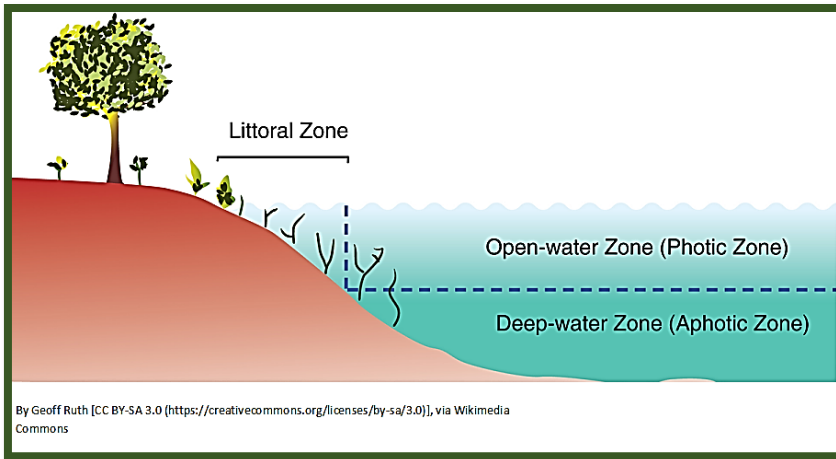
Largest of all biomes and it covers 70% of our planet!

Marine algae supply much of our oxygen and take in a great deal of CO₂.

The oceans are large bodies of water that we separate into zones:

- 1) **Intertidal:** ocean meets land here to form a shore. Also called the “littoral” zone, this is here the waves form and crash to the shore!
- 2) **Pelagic:** open ocean, many fish, whales and dolphins. Primary plant is the photoplankton. The zone includes three main layers based on how much light enters:
 - a) Euphotic: photosynthesis occurs, bright sunlight!
 - b) Dysphotic: some light, but not enough for photosynthesis
 - c) Aphotic: darkest area of the ocean, no photosynthesis
- 3) **Benthic Zone:** bottom of the sea and sea floor, it is made up of sand and sediments. Major food for species that live here is dead organic matter called detritus. Marine organisms living here like crabs and clams are called benthos.
- 4) **Abyssal Zone:** the deep ocean, highly pressured and very cold, invertebrates and fish do live here, however

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★ **Estuary:** where freshwater and saltwater merge, usually where a river meets an ocean!!

What is Lake Turnover?

This is a process seen in which the lake's water turn from top to bottom.

Lakes are “layered” with respect to temperature and this affects the amount of dissolved O_2 .

In Spring and Autumn lake waters are well supplied with oxygen at all depths

In winter and summer, O_2 is highest at the top and lowest in deeper waters. **Know this for the DAT and you will be fine.**



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What is eutrophication?

This is an enrichment of a body of water with nutrients, usually in excess. The nutrients usually involve: nitrogen and phosphorus.

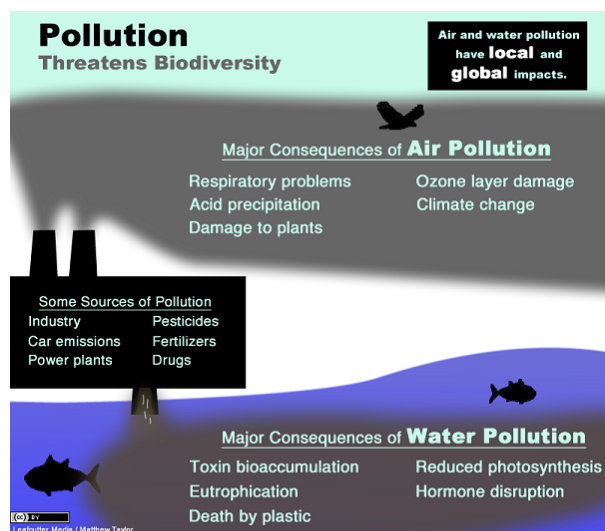
This leads to an increase in growth of organisms such as cyanobacteria and algae. This usually changes the biotic and chemical character of a body of water such as a lake for the worse. Noxious blooms of cyanobacteria are often seen stimulated.

Eutrophication is almost always induced when phosphate-containing detergents, fertilizers, or sewage is introduced into an aquatic environment. As an overgrowth of life and plants occur, O₂ levels are depleted. When algae die, micro-organisms use O₂ to decompose them. Clearly, you see how O₂ is depleted. Algal blooms usually mean a lack of O₂, and fish die. Waters become cloudy and colors of yellow, red, brown, and green are often seen.



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Clearly, stricter laws on phosphorous use and agricultural use of fertilizers must be enforced.



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Although not a favorite topic among students, this biome material is tested on the DAT exam.

Hopefully, I gave you a good idea of what it is all about. I invite you to add to this, download pictures of a Savanna for example, look at the alpine tundra at the top of that mountain, look at areas where you find a rainshadow. A little imagination and creativity will make this area not only more exciting, but fun!

Chapter 41- Animal Behavior

Animal Behavior



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Behavior

What is behavior?

This refers to how an animal acts in response to a particular situation or to a given stimulus.

An animal's behavior is determined to a large extent by its anatomy and physiology. Genetic as well as environmental factors are clearly involved.

Ethology is the study of animal behavior.

Genes influence behavior since they control how an animal is to be built, i.e. its anatomy.

The animal can detect and process information since it has sensory receptors, along with nervous and endocrine systems that issue commands to make the appropriate response.

Hormones contribute greatly to behavior. For example, singing in birds. Songbirds such as white-throated sparrows have singers that are mainly males. Hormones such as estrogen and progesterone cause differences in brain region which accounts for the fact as to why only the males sing. In addition, male testes make more testosterone which binds to receptor cells also involved with song.

Birdsongs can vary by geographical location, age, and time of the year.

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The Avarian vocal organ is called the syrinx, a bony structure at the base of the trachea.



What is the function of birdsong?

- 1) To attract a mate
- 2) To induce another bird to reveal its sex
- 3) To establish its territory
- 4) To scare away predators
- 5) Species identification

Clearly you see that birdsong is very specific communication.

There are many fine ornithology (study of birds) websites you can check out if you want to learn more about the wonderful sound called birdsong.

Behaviors are able to be classified in several ways. Let us examine a few that you need for the DAT exam. **I have also written up a few questions in the DAT Destroyer that will surely delight you.**

Instinct: this is an unlearned behavior or response triggered by a specific stimulus. It is believed to be genetically determined.

e.g. a chick pecks at the parent's beak to get food

e.g. moving your hand away from a hot stove

Learned behavior is acquired or eliminated as a result of an experience. This type of behavior can change with time (ask any politician).

Innate behavior (instinct) does not change with time and occurs rapidly without mistake.

Often it is quite difficult to disentangle an instinct from a learned behavior. **Remember:** a learned behavior involves an experience and an environment. No experience necessary for an instinct!!

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Fixed Action Pattern: acts that are performed in identical fashion. Reflexes are the simplest fixed action pattern (much work was done in this area by Niko Tinbergen).

A sign stimulus (releaser) will initiate a fixed action pattern to trigger!!

A red object causes a male stickleback fish to attack. The red object is the sign stimulus, or releaser.

Some mating dances by birds are fixed action patterns. The sign stimulus is the bird of opposite sex.

Some moths instantly fold their wings and drop to the ground if they hear ultrasonic waves such as those produced by bats.

Migratory behavior of birds is another example!

These complex innate behaviors are known as fixed action patterns. Fixed action patterns are:

- 1) Highly stereotyped
- 2) Instinctive behaviors
- 3) Triggered by a sign stimulus (they can be extinguished if the sign stimulus is removed)

Kinesis and Taxis

Kinesis: A simple activity change in response to a stimulus. It is non-directional.

e.g. with increased humidity, woodlice move slower.

e.g. Pill bugs move toward a moist region

Taxis: Is movement that is directional.

- a) + taxis: moves toward a stimulus (e.g. fish swim toward the current)
- b) – taxis: moves away from a stimulus (e.g. an organism moves away from a light source)

Kinesis has random and undirected motion, while taxis has specific and directed motion.

A phototaxis involves movement in response to light, a chemotaxis involves movement in response to a chemical and magnetotaxis involves movement in response to a magnetic field. Some bacteria actually use the Earth's magnetic field to determine position.

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Migration



A regular, long-distance location change often seen demonstrated by fish, birds, and some animals. They are expeditions that start and finish in predictable places at certain times of the year. Hundreds of miles could be traversed of land and sea.

Bees and birds, for example, can move in a specific compass direction. The direction of the sun and stars can aid in their ability to know direction. Some scientists suggest that the Earth's magnetic field can act upon the photoreceptors of animals. Baffled? Don't feel so bad, so are the scientists!!

The availability of food or environment temperature or a combination of both will often trigger migration to occur.

Imprinting



This type of behavior has both innate and learned components. However, the stimulus is experienced during a **critical time period**.

Usually, the animal is exposed to a specific key stimulus early in its behavioral development and forms an association with the object. It is difficult to modify through later experiences.

Chapter 41- Animal Behavior

e.g. A baby geese is born and they see you. Suddenly, they begin to follow you wherever you go, thinking that you are their mother!! This demonstration of graylag geese was first done by Konrad Lorenz... the Father of Ethology.

Imprinting is done rapidly and must occur during a definite critical period after hatching.

Almost a sure bet DAT question peeps!

Habituation

This is the loss of an old response. Animals learn to simply stop responding to a repeated stimulus that are not important to them.

One of the simplest... if not the simplest form of learning.

It has an advantage in that it increases the animal's reaction to new stimuli. Some examples:

Urban birds learn not to flee from cars or humans that pose no threat.



A clock makes a humming sound, but after a while you pay less and less attention to it.

Your neighbor has an air conditioner that makes a buzzing sound, over the next few days you simply tune it out.

★ Habituation is non-associative learning. In other words, there is no reward or punishment associated with it. A few theories have been presented as to what the purpose of habituation is.

I like what is called the “dual-factor” theory. Our brains realize that the stimuli can neither help nor harm us. The brain is then able to focus on other stimuli that may be a danger. **At any rate, make sure you know this for the DAT... and you are sitting pretty!**

Chapter 41- Animal Behavior

Courtship and Mating



By Brian Ralphs from Berkhamsted, Hertfordshire, UK
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Most vertebrates, birds, and fish in particular prefer to maintain some reasonable distance between themselves. This applies to the same species or a different species. Have you ever noticed birds on a telephone wire? There is space between them, they are not that close.

Even when flying in the sky, birds maintain their distance, as do fish swimming in schools tend to keep a reasonable distance.

Complex behavior patterns called **rituals** or **ceremonies** occur. One function of a mating ceremony is to “make nice” with the prospective mate and attempt to allay any feelings of hostility. A mating ceremony often consists of:

- 1) Aggressive
and
- 2) Appeasing behavior

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If, for example, a certain fish exhibits a “zig” movement toward a female, it is taken as an act of aggression. If a fish “zags”, it is taken as an act of “kindness”.



Courtship behavior can be fascinating to watch. Courtship behavior can involve:

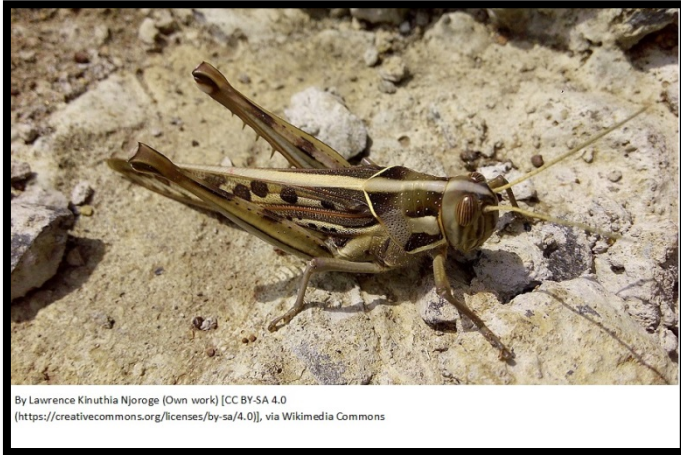
- 1) Mating dances: from simple to very elaborate
- 2) Unusual Displays: Flamboyant colors, raising the chest, or flaring of wings
- 3) Nest building: nest decorating with moss, pebbles, and even flowers have been observed!!
- 4) Singing (who doesn't love a great singer?)
- 5) Preening: close contact between the pair can defuse aggression
- 6) Feeding: the male bird might bring the female bird a tasty treat

The Campbell book went into some very long-winded explanations, but this is essentially what you need to understand for the DAT.

Hopefully, you can now begin to see that courtship behavior is tricky business!

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Insects



Do insects do the same as birds? The answer is no.

Insects are very numerous, and effort is required to finding a mate. Females often have many willing “suitors” to choose from. If the male insect wants to pass his genes, he must attempt to stand out in the “crowd”. Insects may do:

1) Serenades

Crickets love to sing- they use distinct calling and courtship songs. Even fruit flies and mosquitoes get into the singing act!!

2) Dancing and Foreplay

Spiders, believe it or not, are very good dancers. Certain flies can do elaborate zig-zag dance moves in hopes to “impress” the female.

Foreplay? You heard me!! Some female insects the love feel of an antennae. Springtails, which are no longer considered insects, but arthropods, actually touch each other with their antennae!!

3) Gifts

Some insects capture food and present it to the females.

4) Pheromones (“Social Hormones”)

Not only common to insects, but to **mammals** too!!

Not limited to short distances, but a certain female moth can attract a mate by a mile or more!! Pheromones can induce courtship behaviors.

Queen bees use pheromones to attract male honeybees (drones)... thus acts as a sex attractant.

Hopefully, you can see that pheromones may evoke:

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- A) Behavior responses
- B) Developmental responses
- C) Reproductive responses

In mammals, females often emit an odor during their time of fertility and sexual receptiveness. The dogs (males) go nuts!! They often will bite, scratch, jump over fences... sell their damn soul to Satan.. just to reach the female in estrus.

Pheromones can also be used to “mark” the territory of an animal. Many cats and dogs urinate in an area to make their “claimed land”.

Ants often mark their path with pheromones as do caterpillars.



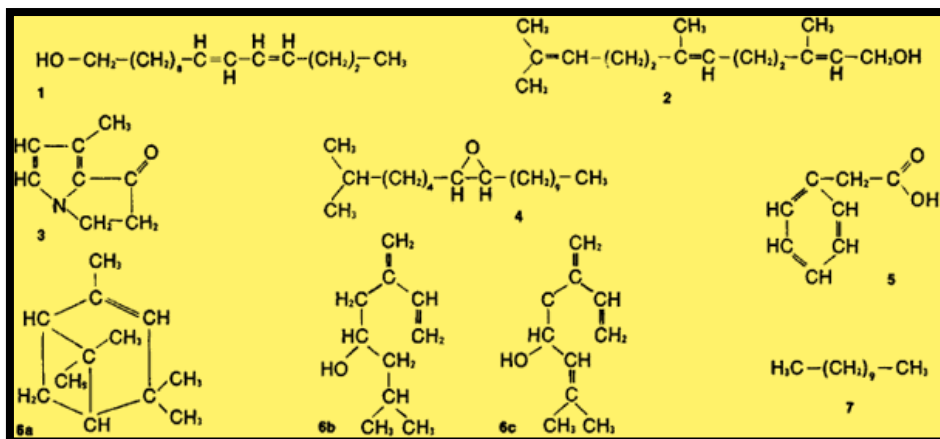
Do pheromones have any particular molecular structure?

No! They can be very simple such as HCOOH (formic acid) in the ant to very elaborate structures with many functional groups we recognize from organic chemistry.

Let's just have a peek... **no need to memorize this**... just understand the concept.

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Here are a few of thousands of different pheromones:



Relationships between males and females vary a great deal from one specie to the next.

I know that you are burning to know:

Is monogamy the rule; one man to each woman?

In many species, there is mating that is promiscuous with no strong bonds or lasting relationships.

If the mates happen to remain together for a long time, monogamy is seen and surely not impossible.

Polygamous relationships are also common. The polygamous relationship usually involves a single male and many females.

In a polyandrous species we see a single female mating with several males.

Birds seem to be the most “behaved”, as monogamy is most common... 90%!!

However, they don’t stay together for life. Often their “bond” is for a single breeding season.

Believe it or not, many books are written on this. A simple google search will lead you to bird marriages, bird infidelities, even bird divorces!! **For the DAT, we are set.**

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Associative Learning

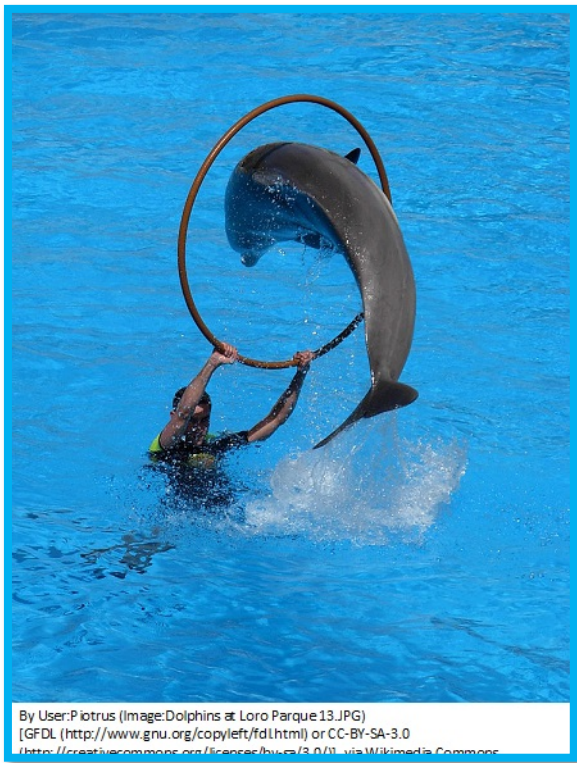
This is a type of learning in which one stimulus becomes linked to another through experience. In other words, ideas and experiences reinforce each other.

It is indeed a form of conditioning resulting in a behavior being learned or unlearned based upon the response it generates.

2 types of associative learning:

- 1) **Operant conditioning**
- 2) **Classical conditioning**

Operant Conditioning



In **operant conditioning** (trial and error learning) the animal learns to associate its behavior with a reward or punishment. This is the basis for most animal training.

Let's do some examples:

Reward (Positive Reinforcement): A teacher gives a gold star on the paper of a student who gets all the problems correct on the exam.

A rat presses a lever in the B.F. Skinner experiment and got food as a reward.

A dolphin receives a tasty treat for jumping through a hoop.

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A dog stops barking each time it gets a treat.

Punishment (negative Reinforcement):

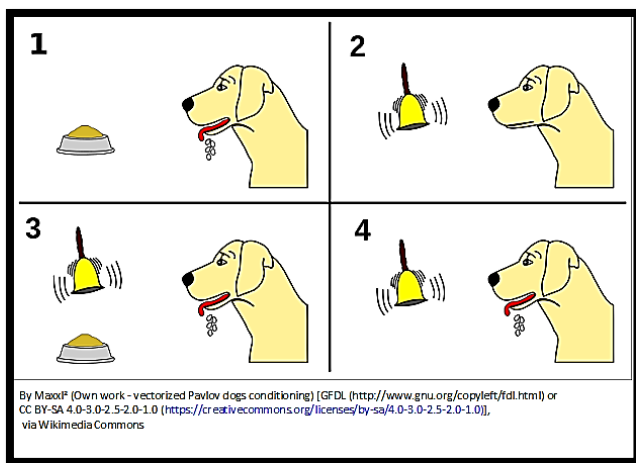
Students must stay after class if they misbehave.

A child gets punished for trashing his room.

Classical Conditioning

Here, we form an association between two stimuli resulting in a learned response.

Consider the famous Russian physiologist named Ivan Pavlov. Food was given to a dog. The food (unconditioned stimulus) produced salivation (unconditioned response) in the dog, where a bell (conditioned stimulus) was rung. The bell alone eventually produced salivation in the dog!!



Let's do one more example.

Every hour, an army officer fires his gun and makes a soldier cringe. The officer fires four times. The soldier cringes on the first three.

However, on the fourth try, the army officer did not fire, but the soldier still cringed!!

This is classical conditioning. Cringing is the conditioned response, while the gun is the conditioned stimulus.

Extinction could occur if the army officer assures the soldier of no more firing. In extinction we see a gradual weakening and disappearance of a conditioned response.

Chapter 41- Animal Behavior

Foraging Behavior

The searching for wild food resources... it includes eating and the way an animal searches for and captures food.

Genetic and environment both contribute to this behavior.

Foragers balance the risk of being killed by other predators with their own needs.

Foraging can be:

- 1) Individual: capture and consume prey alone
- 2) Group: capture and consume prey among other members

In nonhuman primates, young individuals learn from older animals or even their peers.

★ The first assumption of optimal foraging theory is that natural selection will only favor behavior that maximizes energy return.

Animals that forage and survive contribute genes to the next generation, while the genes from animals that die are eliminated.

Hopefully you can see that successful forages are favorable by natural selection.

Social Behaviors

Here we deal with interactions between animals.

Agonistic Behavior

This is social behavior relating to fighting. It includes:

- a) Threats
- b) Displays
- c) Retreats
- d) Playing “nice”
- e) Making up

Why do they fight? Animals often fight for two main reasons: **food and mate finding**.

In this behavior we see threats, aggression, and submission.

Believe this or not, but physical fighting is not that common between animals. To avoid the heavy cost of fighting, animals have evolved many elaborate rituals by which they use to “bluff” their opponents into fleeing. These rituals are used in disputes involving:

- a) Territory
- b) Food
- c) Mates

Examples:

Chapter 41- Animal Behavior

A primate becomes vocal and uses hand gestures to scare an opponent.

An animal stands on its hind legs as an opponent nears.

A bird spreads its lower tails and fluff its feathers when it's territory is breached.

A gorilla begins pounding on his chest as another gorilla approaches.

Dominance Hierarchy



Vertebrate societies are often arranged in hierarchies. A “ranking” system is often created. A social order is created and can indeed change if the dominant animal is challenged.

In baboons, higher-ranking males have the highest reproductive success since they acquire the most females. Higher-ranking animals have more access to fertile females, and can partake in matings.

Dominance hierarchies are known in bees, wasps, and many insects as well.

The main function of a dominance hierarchy is the maintenance of group stability.

Body size, which often correlates with the fighting ability is an intrinsic factor in the establishment of a dominance hierarchy. When dealing with animals, such as chickens, the term “pecking order” is often used. The top ranked chick controls the behavior of the others! The alpha chicken can peck any in the flock, and the beta chicken can peck all the others, except the alpha.

For birds:

- 1) Males are dominant over females
- 2) Adults are dominant over the young

Chapter 41- Animal Behavior

Altruistic Behavior



An animal risks its safety and life to protect and save the others.

The fitness of the group is increased at the expense of the individual animal.

★ When an animal helps another, it is almost always another relative.

How could such behavior evolve? Close relatives have genes in common, thus altruism promotes the survival and transmission of genes. This is called **kin selection**. Many of the relatives have similar genes to the animal that sacrificed themselves. In kin selection, we see the kin as the recipients of genes that will be able to be passed down.

Let's do some examples of altruistic behavior:

A honeybee stings a person trying to harm a beehive. When this happens, the honeybee dies because the stinger is pulled from the abdomen of the honeybee.

What is biological fitness?

This is the contribution that an individual makes to the gene pool of the next generation relative to the contributions of the other individuals. Essentially, it involves an organism, or more rarely species, to survive and reproduce in their given environment.

Chapter 41- Animal Behavior

Territoriality

The territory is the sociogeographical area that an animal of a particular species defends.

The area or territory defended by the animal is used for purposes such as:

- 1) Nesting
- 2) Mating
- 3) Feeding
- 4) Hunting

Most vertebrates and some invertebrate such as insects exhibit territoriality behavior.

These territories are defended against by agonistic behaviors already discussed. A territory holder will attack and drive away other members of the same species. However, aggression must be controlled. Why? Every attack carries the risk of injury or death. These agonistic behaviors are usually employed most often. A nice example is the Adelie penguins of the Antarctica. Each bird defends a small territory, even if it is just a single nest and a few inches of feet around it!

What is an appeasement gesture?

This is a gesture made by the weaker or subordinate individual. Essentially, it calms a situation down!!

Dogs may yawn or lick their lips to show they come in peace.

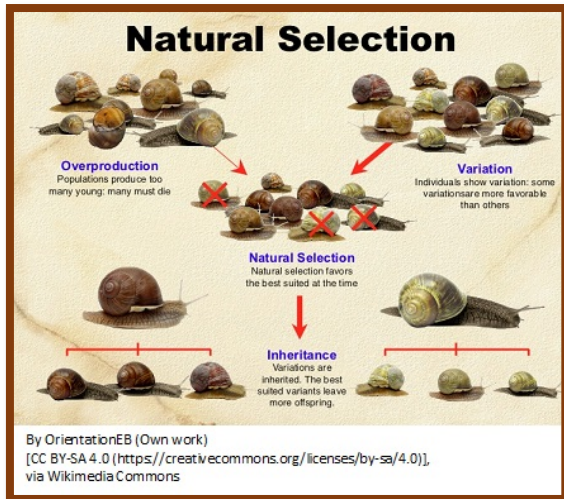
A submissive posture can alert the dominant animal that they know who is boss! An animal puts its head down or turns around when another animal threatens. Humans often use appeasement gestures to stop a fight. For example, they cower, whine, cry, or display a nervous laugh.

Thus, the concept of sociobiology teaches us that most aspects of our social behavior do indeed have an evolutionary basis. The concept is debated by many, however.

Chapter 42- The Formation of Species

The Formation of Species

Natural selection will have an impact on populations over time. The key point here is that populations evolve, not individuals!!



Microevolution vs. Macroevolution

Microevolution happens on a small scale within a single population. The changes would not result in the newer organisms being considered as different species.

e.g. A species has a color or size change. Thus, genes in a gene pool of populations = microevolution.

Macroevolution refers to major evolutionary changes over time. A whale is a descendent from a land mammal is a fine example. A new specie forms = macroevolution.

A **species** represents a population of organisms that may display a range of genotypic and phenotypic variation, and members have the potential to interbreed and produce viable and fertile offspring. Species exist as a discrete unit in nature!

It is possible for two species of a population to evolve in different ways. As time goes on, they become more and more different until they can no longer interbreed. This is **speciation**.



The defining characteristic separating one species from another is they are **reproductively isolated**.

Favorite DAT-type question.

Reproductive isolation is a major working criterion for species definition, but it is not perfect.

For example, sometimes, occasional mating does occur between members of two different species. However, most of the offspring are sterile and have no evolutionary future.

A male donkey ($2N = 62$) and a female horse ($2N = 64$), produce an offspring called a mule. Can you tell me the $2N$ chromosome number of a mule? Donkey gives 31, horse gives 32 (recall half of the chromosomes come from each parent). Thus, the mule has $2N = \underline{63}$.

Chapter 42- The Formation of Species

(You may one day thank me for this example, LOL.)

The reproductive isolation criterion is for organisms that do sexual reproduction, thus a shortcoming is that it cannot be applied to organisms that reproduce asexually. Nevertheless, it remains as the major criterion for species definition.

Let us look at speciation.

Allopatric Speciation

Interbreeding between populations is prevented because of a **geographical barrier**. Gene flow cannot occur. These geographical barriers can include:

- 1) Rivers
- 2) Oceans
- 3) Mountains
- 4) Deserts
- 5) Glaciers
- 6) Canyons and ranges
- 7) Altitude or longitude

Say for example, two squirrel species are noted on opposite rims of a canyon. Unlike the birds, our squirrel friends were not able to cross. The barrier is the canyon, this now sets the stage for allopatric speciation.

Sympatric Speciation

Different species are produced from populations that occupy the same geographical area.

No geographical boundaries!! This is less commonly seen than allopatric speciation.

Gene flow is reduced by several ways:

A **polyploidy** can occur, whereby a mistake during cell division results in an extra chromosomal set. Thus, a plant for example, has a $4N$ chromosome number, instead of $2N$. These $4N$ cells cannot breed with $2N$ cells, but the $4N$ cells can produce fertile offspring by self-pollinating or mating with other $4N$ cells.

2 forms of polyploidy:

- a) Autopolyploidy
- b) Allopolyploidy

Autopolyploidy: organism has more than 2 sets of chromosomes all derived from a single species.

e.g. AAAA

Additional chromosomal set that is identical to parent species. e.g. if Plant X has a $2N = 10$, a new species Y, arises as an autopolyploid from X has a $2N = 20$.

Allopolyploidy: organism has more than 2 sets of chromosomes, derived from different species.

e.g. AABB is the chromosomal composition.

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I hope you can see this. The organism has another set of chromosomes from another species.

I have put a nice question on this in the Destroyer. Make damn sure you do every problem.

Sympatric speciation can also occur if:

Reproductive isolations occur due to natural selection. For example, a mutation causes a “shift” in the timing of reproduction or even a “shift” in food preference. Individuals are in a situation which may cause breeding among themselves only.

This can also occur if herbivorous insects try out a new plant host. By exploiting a new niche, such as this could trigger sympatric speciation.

Consider a bacteria population. If some bacterial members are specialized for living in a certain environment, this population may go on to occupy a different environmental niche and could indeed evolve into a new species over time.

A recent example I found for you of sympatric speciation occurred with apple maggot flies. These flies lay eggs on Hawthorn trees, but less than 200 years ago, they began to lay eggs on apples. Guess what? Yes, indeed!! Two groups of apple maggot flies have emerged.

One group lays eggs on Hawthorn trees, the other group lays eggs on apples. The groups were studied by scientists and have shown to have genetic differences. It is very possible that in the future, we could see separate species!!

Bottom Line: Speciation can occur even when different populations of the same species are in the same geographic boundary.

For the DAT, make sure you clear between allopatric and sympatric speciation.

Is speciation slow or fast?

It can occur rapidly or slowly and it can involve a few genes or many!

Speciation Models

Two models deal with speciation:

A) Gradualism

A common ancestor is involved which over a long period of time gave rise to current organisms.

Many small changes occurred during the process and some cases are well documented in the fossil record. However, the fossil record also will include many episodes in which a new specie suddenly appears in rock layers, persist in many layers, then are gone!! A new model was developed.

B) Punctuated Equilibrium

After a period of equilibrium, evolution is concentrated in very rapid events of speciation.

Chapter 42- The Formation of Species

Thus, one model is a proponent of long-term gradual adaptive trait accumulation (gradualism), and the other model claims short periods of rapid specie formation occurred, separated by times of equilibrium.

Which model is better? Studies are showing that the punctuated equilibrium model is favored!

★ Punctuated equilibrium explains the variations that is seen in the tempo of speciation!!

For those who would like to see evidence of this, the Campbell book has a chapter entitled, “The Origin of Species”. It is well-written and a delightful read.

Coevolution

What is coevolution?

This is evolution of two or more species whose members exert selective pressures on one another. Let us consider a few examples so that you are clear on this important concept.

Coevolution likely will occur when different species have close ecological interactions. Coevolution occurs in:

- 1) Predator-Prey relationships
- 2) Host-Parasite relationships
- 3) Mutualistic species

Many plants and insects (the pollinators) are so reliant on each other that their relationship is “exclusive”.

Bumble bees pollinating flowers, and the Acacia Ant living on the Acacia tree are examples. They depend on each other for survival. The ant protects the tree from certain insects while the tree provides nourishment for the ant!!



By Dohduhah (Own work) [Public domain], via Wikimedia Commons

Chapter 42- The Formation of Species

Hummingbirds love a certain flower- the flower has nectar suited to the bird's diet and their shape fits perfectly with the bird's bill!!

Predator and prey evolve together! The predator will die if there was no food (prey). Thus, it evolves things like speed, good eyesight, or good hearing to hunt, kill, and eat the prey.

The prey also evolves what it needs to in order to survive!! Prey develops speed, smell, sight, camouflage, thorns, poisons, etc.

I hope I communicated and drove this point home to you all. Coevolution between different species is universal, but the best studied examples are between insects and flowering plants.

Much of the evolutionary success of flowering plants is due to the fact they have coevolved with animals.

Prezygotic Barrier

What is a prezygotic barrier?

These are barriers that prevent members of different species from mating.

For example, we can have “**mechanical isolation**”. If for example the two animals differ greatly in size... i.e. incompatibility of genitalia or two flowers which have different floral anatomy.

Another prezygotic barrier is **habitat isolation**. The two species live in the same area, but one prefers water, while the other prefers land. They simply do not encounter each other.

Behavior isolation is another prezygotic barrier. Perhaps a species dances a certain dance, sings a certain song, or gives off a certain pheromone which is only unique to that particular species.

Gamete isolation is yet another prezygotic barrier. The sperm and ova of the two species are chemically and genetically incompatible and no zygote forms. If not for gamete isolation, any sperm in the water could fuse with any egg, and we'd see hybrids of marine creatures abound!!

Temporal isolation is yet another prezygotic barrier. Here we see breeding at different times of the day or night, or different seasons. For example, a species of skunk mates in the winter, another mates in the summer.

Clearly, you now understand prezygotic barriers.

Postzygotic Barrier

What is a postzygotic barrier?

Once mating has occurred, a post zygotic barrier prevents the production of fertile offspring.

e.g:

A) Reduced Hybrid fertility... the hybrid is sterile

B) Hybrid Viability: the hybrid dies prematurely (e.g. mating between two frog genus results in offspring with incomplete development)

C) Differences in chromosome number due to incorrect pairing during mitosis or meiosis

Chapter 42- The Formation of Species

Both prezygotic and postzygotic barriers result in reproductive isolation.

Extinction



What is extinction?

This is the end of an organism or the end of a species.

We have looked at how species arose through the process of evolution. Now species were able to thrive when they find and exploit an ecological niche.

In extinction, we find the organism unable to survive in changing conditions or perhaps against a stronger competitor for resources.

Certain times in our history have seen the elimination of major life forms. The dinosaurs disappeared at the end of the Mesozoic era is a great example!! **(A must have fact for the DAT!!).**

Extinction is proceeding at a far more rapid rate than ever before due partly to human predation and destruction of natural habitats.

Many scientists have estimated that up to 50% of presently existing plants and animals could be extinct by the year 2100.

Are you curious what animals are extinct? I was... and I did a Google search. Have a look at what I found!! Amazing, but sad indeed!!

Chapter 43- Evolution

Evolution

The Earth is approximately **4.5 billion years old** and has undergone major climatic and geographic changes.



The fossil record shows the remains of past organisms.

As of November 2017, the oldest dated fossils have been estimated to be approximately 3.8 billion years old. Microscopic filaments and tubes were found.

Previously, it was believed that the cyanobacteria were the oldest known fossils.

At any rate, this gives you an idea of things.

Let's remember these three things:

- 1) Age of the Earth: 4.5 billion years
- 2) First Prokaryotes: 3.8 billion years
- 3) First Eukaryotes: 2.7 billion years

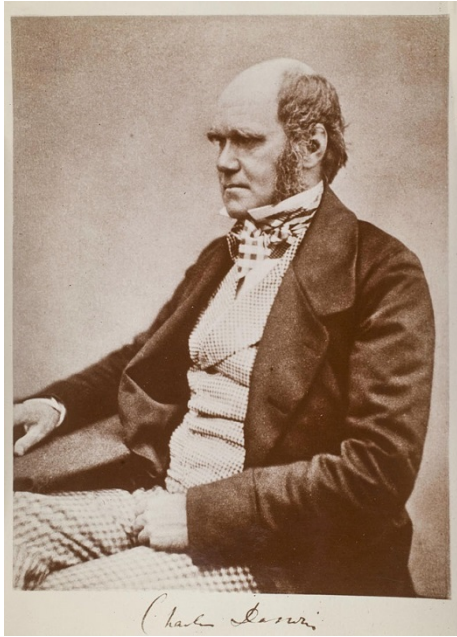
These numbers could indeed change. **If you find any newer information than November 2017, please post it on our Facebook DAT Destroyer Study Group wall.**

A succession of living forms has been recorded in our fossil records. In general, simpler forms preceded complex forms.

The process by which organisms come to differ from one another from generation to generation is called evolution. Sometimes, the definition can be defined a bit narrower to the change in the gene pool of a population from one generation to the next.

Chapter 43- Evolution

Charles Darwin and Natural Selection



Evolution can occur by a mechanism called **natural selection**. This idea was championed by Charles Darwin in his book, “On the Origin of Species”.

Random evolutionary changes are selected for by nature in an orderly and consistent fashion. There are limited resources in nature, thus, those organisms that have traits that favor survival and reproduction will leave more offspring allowing the traits to be passed down through generations.

Thus, natural selection can lead to increased fitness.

The following is what you need to understand about Darwin for the DAT exam:

- 1) The best adapted individuals tend to leave more offspring. (An adaptation is a characteristic of an organism that will increase their chances at survival).
- 2) Competition occurs because so many individuals are introduced into an environment of limited resources (the stronger animal prospers!)
- 3) Food resources in the environment are limited, thus there will be a struggle for survival (the better hunter more likely will live).
- 4) The number of offspring emerging in an environment tends to be greater than the environment can support (the less efficient organisms tend not to survive).

For those that want to pursue this in greater detail, I recommend the Campbell text. The book does a wonderful job with many photos.

★ In his publications, Darwin wrote mainly about adaptations.

Natural selection is ongoing, and can be seen when looking at certain pathogens such as bacteria or viruses.

Some bacterial and viral particles can become resistant to a drug, and multiply rapidly.

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Rapid multiplication increases the frequency of drug-resistant organisms, they literally “figured out” how to survive!

Another evidence to evolution is the fossil record, we can see how past species differed from one another and note any evolutionary changes that occurred.

What is a cetacean?



This is a clade of mammals that are aquatic and include the dolphin, porpoise, and whale. Cetaceans evolved from four-legged terrestrial animals. Forelimbs are still present, but are reduced to flippers. Male genitalia has also evolved, it moved internally. The cetaceans spend a short time only at the water surface, where they exhale into an explosive “blow”.

Paleontologists study fossils and these fossils convey to us much scientific information.

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Jean-Baptiste Lamarck



Another scientist to know for the DAT is Jean-Baptiste Lamarck. Lamarck studied fossils and was the first person to develop a theory regarding change in plants and animals over time.

However, he is known for his theory that is now considered wrong called the “Theory of Acquired Characteristics”.

If an organism changes in order to adapt to the environment, these changes are passed down to offspring. If for example, giraffes stretched their necks to reach food, the later offspring generations would have long necks.

It was not understood how genes were inherited, Darwin did not reject the Lamarck theory, but put the natural selection as the evolution mechanism.

Lamarckian theory has been discredited. According to Lamarck, a bodybuilder would likely have a child that is strong and muscular.

Lamarck also proposed the idea of **use and disuse**. If you don’t use it, you lose it. This idea is basically correct.

Lamarck also believed organisms move toward greater complexity. This idea was proven incorrect.

We now understand about natural selection.

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Artificial Selection

What does artificial selection mean?

Artificial selection is when humans modify a species. In artificial selection, we give a population desirable traits. Artificial selection is seen in:

Plants: superior crops of corn, soybean, and wheat have been produced. Flowers such as roses produce “hybrid” roses. If any of you are ever in Norfolk, Virginia, stop by the Botanical Gardens and see the hybrid roses in the rose garden... or see it on YouTube!!

Animals: the meats many people eat are the result of careful selective breeding of pigs, cows, chickens, turkeys, and sheep. Cats without fur can be produced for those that are allergic.

Homologous and Analogous Structures

This is a must have for the DAT exam.

Homologous: these are structures or organs that are similar in morphology (shape), anatomy, genetics and embryology, but have different functions. ★ They may even look different.

They have a common ancestor. The relationship between homologous structures is termed homology.

Homologous structures include:

- 1) Flipper of a whale
- 2) Wing of a bat
- 3) Leg of a cat
- 4) Arm of a human

When these are compared to each other, you are dealing with homologous structures.

Analogous: these are structures with the same function but evolved separately... they also have a similar appearance

No common ancestor

Analogous structures include:

- 1) Wing of a bat and wing of a bird
- 2) Wing of an insect and the wing of a bird
- 3) Fish fins and whale flippers
- 4) Jointed legs of insects and vertebrates used for locomotion
- 5) The spine of a cactus and thorn of a rose

Carolus Linnaeus first began classification of species with **taxonomy**. All similar looking species were grouped together. Clearly, this was the incorrect way to classify species. Similar looking structures may have not evolved at the same time. Hopefully, you all see that just because two structures look alike (bird wings

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and insect wings) does not mean they share a common ancestor. Butterfly wings and robin wings are only superficially similar, and perform the same function.

Analogous structures evolve due to what is called **convergent evolution**. In convergent evolution, we see organisms that are not closely related independently evolve similar traits as a result of having to adapt to similar environments or ecological niches. The North American cactus and the African Euphorbia plant look alike. Both plants developed in harsh, arid desert climates, but both experienced convergent evolution!

In **divergent evolution** we see an ancestral species form into a number of different species with both similar and different traits. Darwin's finch birds on the Galapagos Archipelago are a great example.

Bottom Line:

Divergent evolution: common ancestor

Convergent evolution: no common ancestor

Which organism is more evolutionary successful...?

- A) Lays 10 eggs, 8 hatch, 2 reproduce
- B) Lays 6 eggs, 4 hatch, 3 reproduce

I hope you said B!! We want offspring if we are to have “**fitness**” and be evolutionarily successful.

Human DNA sequences and chimpanzee DNA sequences are very similar. **What does this suggest?**

They share a relatively recent common ancestor!!

The best technique to determine the phylogenetic relationship between 4 species A, B, C, D would be?

I hope you said DNA Analysis and examination of protein comparison!

Evolution is indeed supported by much scientific evidence. This evidence can come from several sources:

- 1) Taxonomy: naming and classifying organisms
- 2) Molecular Biology: studies molecular structures
- 3) Paleontology: studies fossils
- 4) Biogeography: studies past and present specie distribution
- 5) Genetics: studies genes and DNA
- 6) Comparative anatomy: studies different structures

What does the term “Ontogeny Recapitulates phylogeny” mean?

It means that in the course of development, an organism goes through the same successive stages as did the species in its evolutionary development.

It was formulated by E.H. Haeckel.

The organism actually expresses all the in-between forms of its ancestors throughout evolution (phylogeny).

If “ontogeny recapitulates phylogeny” was completely true, a chick would go from a single celled organism to a fish, then to a reptile, then a bird, then a chick.

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Clearly, this is not the case. This theory has many shortcomings since embryos evolve in different ways. Thus, this theory is essentially not true.

Vestigial Structure



A **vestigial structure** has little or no importance to an organism.

They had important functions in ancestors, however.

e.g.

1) Wisdom teeth in humans

2) Coccyx (tailbone) in humans

★ 3) Appendix. This is a bit controversial since current data suggest that it might have an immune function which includes acting as a “storehouse for bacteria” ... this could be beneficial. The debate continues!

If you examined a cave-dwelling animal which organ do you think would most likely become vestigial?

a) Ears b) Mouth c) Eyes d) Legs

I hope you said eyes!! Caves are dark... eyes might not be needed!

Chapter 44- Evolution and Populations

Evolution and Populations

Populations evolve, not individuals. However, natural selection acts on the individual.

The smallest scale that we can define evolution is termed **microevolution**. Microevolution is change in allele frequencies of a population over generations.

What exactly is a population? This is an interbreeding group of individuals that occupy a geographical area.

The gene pool is all the genes available for reproduction in a population.

Variation

★ Sexual reproduction and mutations (a change in the nucleotide sequence of an organism's DNA) produce the genetic variation that makes evolution possible. Most genetic variations are **not** due to mutations, but due to sexual recombination of alleles that are already in the population.

Two or more forms of a phenotypic characteristic in a population is called a morph. A population is said to be **polymorphic** for a characteristic if two or more morphs are found in noticeable numbers. Freckles is a good example.

If two or more snakes differ in color from a single population, we are looking at polymorphism. ABO blood groups is another example. This balanced polymorphism can indeed allow for diversity or variation of a population's gene pool.

Besides mutation, and sexual reproduction, what else can allow for variation?

Heterozygote Advantage: the hybrid is selected for because it has a higher reproductive rate

e.g. in areas where there is malaria, the heterozygote is favored by natural selection and hence resistant to malaria.

Frequency- Dependent Selection: here we see the survival and reproduction morph decline if that phenotype becomes too common in a population.

If, for example, a butterfly with a certain color pattern is being killed off by birds, the frequency of other color patterns would increase

Geographic Variation: e.g. 2 different varieties of mice exist in two different areas of the United States separated by mountainous terrain.

This is where we see an **ecocline** or just **cline** for short. Clines consist of forms of species that show gradual phenotypic and/or genetic differences over a geographical area. Rabbits in the North might have white fur, while the rabbits in the South have a brown fur... such a gradual difference in appearance is a good example of a directional cline. (Plant sizes decrease as you climb up a mountain is an example of a cline, too).

Hopefully now, you see variation is needed for a population to evolve as environmental changes can also dictate.

Chapter 44- Evolution and Populations

Hardy-Weinberg Principle

In order to study whether natural selection or possibly other factors are at work and causing evolution to occur, we need to examine a population that is not evolving.

The gene pool of a population that is not evolving can be described by the **Hardy-Weinberg Principle**.

This principle examines **gene pools** of a population and is **not** concerned with genotypes or phenotypes of specific individuals within the population.

According to the Hardy-Weinberg Principle, the genotypes and allele frequency in a given population will remain constant from one generation to the next, providing that only Mendelian segregation and recombination of alleles operate.

This is important to know for the DAT exam!!

Let us now examine the **five** Hardy-Weinberg conditions:

- 1) Large Population: gene frequency doesn't change as a result of chance alone
- 2) Random Mating: inbreeding causes little mixing of genes
- 3) No Mutations: a mutation modifies our gene pool
- 4) No Natural Selection: survival differences can alter gene frequencies
- 5) No Gene Flow: no immigration, no emigration, no pollen transfer (If a strong wind blows, pollen can move from point A to point B. We don't want this!! Another example of gene flow would be if a population had an influx of new members).

Obviously, no natural population meets all of these criteria. Departure of any of these five conditions usually results in an evolutionary change.

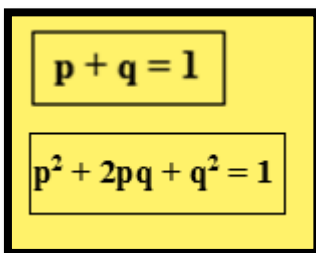
Let us do a few **math problems** that you will be required to do for your exam.

Outside our lab, Hardy Weinberg equilibrium is not likely in nature. However, the idea of genetic equilibrium is a basic principle of population genetics that will provide us with a baseline for measuring genetic change.

Let p = frequency of the dominant allele... A

Let q = frequency of recessive allele... a

For a population in genetic equilibrium we can write:


$$p + q = 1$$
$$p^2 + 2pq + q^2 = 1$$

p^2 = predicted frequency of homozygous dominant individuals in the population

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$2pq$ = predicted frequency of heterozygous individuals in the population

q^2 = predicted frequency of homozygous recessive individuals in the population

These are your two equations that you will bring into the DAT!! Memorize them and I will show some representative type problems.

Problem 1

a) If 16% of a population has green eyes, what percent of the population is hybrid for brown eye color?

16% represents q^2 .

$$q^2 = .16$$

$$q^2 = 16 \times 10^{-2}$$

$$q = 4 \times 10^{-1} = 0.4$$

Thus, $2pq$ is for a hybrid...

We need p ...

$$p + q = 1$$

$$p + 0.4 = 1$$

$$p = 0.6$$

$$\text{thus } 2pq = 2(.6)(.4) = 0.48$$

thus 48% is hybrid!

b) What percent is homozygous for brown eyes?

This is the p^2 term.

$$\text{Thus, } (.6)^2 = .36 \text{ or } 36\%$$

Problem 2

Applying the Hardy- Weinberg Law to a trait with two alleles, a scientist calculated a frequency of 0.2 for the recessive allele. What frequency would the dominant phenotype be in the population?

We are given the q term!!

Careful!! The dominant phenotype will be the p^2 term as well as the $2pq$ term!! They are asking for the phenotype not genotype.

$$p + q = 1$$

p = gene frequency of dominant allele

q = gene frequency of recessive allele

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$$p + 0.2 = 1$$

$$p = 0.8$$

p^2 = frequency of homozygous dominants in a population

q^2 = frequency of homozygous recessives in a population

$2pq$ = frequency of the heterozygotes in a population

$$p^2 + 2pq + q^2 = 1$$

The dominant phenotype will be $p^2 + 2pq$

$$(.8)^2 + 2(.8)(.2) = .64 + .32 = .96$$

Problem 3

A disease occurs in 1/10,000 infants. What % of the population would be expected to be a carrier?

$$1/10,000 = 1 \times 10^{-4} = q^2$$

$$\text{Thus, } q = 1 \times 10^{-2} = .01$$

$$p + q = 1$$

$$p + .01 = 1$$

$$p = 0.99$$

$$\text{Thus, } 2pq = 2(.99)(.01) = .0198$$

$$\text{Thus, } .0198 \times 100 = 1.9\%, \text{ about } \underline{2\%}$$

Thus, 2% of the population or 1 out of 50 can be estimated to be a carrier for this allele.

Problem 4

Assuming Hardy- Weinberg conditions... the frequency of an allele y is 0.3. What % of the population is homozygous for this allele?

We simply look for the q^2 term.

$$(0.3)^2 = .09$$

$$\text{Thus, the answer} = \underline{9\%}$$

I hope you have an idea now as to how to handle these calculations. **I have several more in the DAT Destroyer that you can try.**

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Any deviation from the five conditions listed can cause evolution. Factors like mutations, nonrandom mating, and inbreeding can all affect frequencies of homozygous and heterozygous genotypes, but usually has little effect on allele frequencies in the gene pool.

Very large population	No genetic drift can occur.
No emigration of immigration	No gene flow can occur.
No mutations	No new alleles can be added to the gene pool.
Random mating	No sexual selection can occur.
No natural selection	All traits must equally aid in survival.

Three mechanisms operate to alter frequencies directly and cause the most evolutionary change:

- 1) Natural Selection: fittest survive!!
- 2) Gene Flow: alleles are moved by fertile individuals
- 3) Genetic Drift

Genetic Drift

These are random fluctuations in the relative allele frequencies of a **small breeding population**. Let us consider a population on a small island of only 50 people.

If an allele y is carried by a certain individual who either failed to mate or gotten killed, allele y would be completely lost. This is a genetic drift. This is clearly a microevolutionary process. Thus, the change in allele frequencies in a gene pool of a small population arising from chance events is called genetic drift.

Know this for the DAT!! You will thank me. 😊

In a large population, chance events do not do very much with regard to the gene pool, but can do much if the population is small.

Let me show two examples of how genetic drift can impact a population.

Two extreme cases of genetic drift include:

- 1) Founder Effects
- 2) Bottlenecks

Chapter 44- Evolution and Populations

Let us consider a **founder effect**:

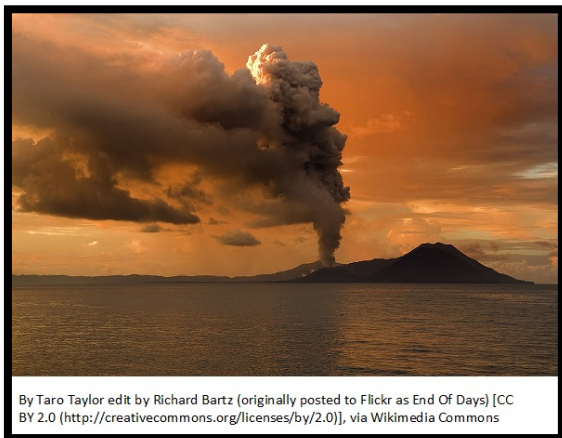


A few members of a parent population may migrate to a new area. Once in the new area, this small population can establish a small, interbreeding population.

Consider a newly formed volcanic island. Seabirds can bring seeds from the mainland. These seeds can now dictate the phenotypic range. When a small population distances itself from a larger one and colonizes the area, it is likely not representative of the original larger population.

In a certain area of Venezuela, there is a high incidence of Huntington's disease. A single woman is believed to have been the “founder” of this population now affected with this pathology.

Let us consider a **bottleneck effect**:



Something bad occurs such as a flood, tsunami, starvation, earthquake, or fire, that reduces the population size. By chance alone, some alleles may be underrepresented, others may be overrepresented, or lost all together. A loss of genetic variation occurs giving rise to a new population that is not representative of the original.

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Let's do some examples...

Northern elephant seals were hunted and reduced to about 20 at the end of the 19th century. Today, over 30,000 exist. However, much less variation is seen than with a population of Southern elephant seals that were not hunted.

European bison faced becoming extinct early in the 20th century. The animals living today have very little genetic variation. They are descendants of 12 individual bison.

And a final example... A volcano wipes out most of an island. Only a small fraction survives. New populations are now built from just these small number of survivors.

Founder effects and population bottlenecks have similar effects: **genetic diversity is reduced**.

Some genes are thrown out, some genes that were once rare, now become common. They are **both random**.

In natural selection, the genes with the best chance of survival are the ones that are passed down to the next generation. In the founder effect or population bottleneck, this might not be the case. The genes that are passed down are not necessarily the “good ones”. I hope I have illustrated this clearly to you.

Fitness

When you think of “fitness” many of you think of a fast runner or perhaps a great boxer. In Biology, “fitness” will mean the **contribution** that an organism makes to the gene pool of the next generation. In a population, the measure of “Darwinian fitness” is the **number of fertile offspring**.

Longevity, strength, speed, etc. is not the true measure.

This is an important point to remember for the DAT exam!!!

Selection on a Gene Pool

Natural selection is indeed the major force that causes changes in gene frequencies within gene pools. Natural selection may have one of three effects on a phenotypic range of a population.

- 1) Stabilizing
- 2) Directional
- 3) Disruptive

Let me illustrate:

In a **stabilizing selection**, the alleles that produced uncommon phenotypes are eliminated over time. Thus, stabilizing selection tends to undo the effects of gene flow, mutation, or genetic drift.

For example:

Babies smaller or larger than the range of 6.5-9 pounds often die.

In the world of birds, robins usually lay 4 eggs each season. More eggs would be bad, parents couldn't provide food for all of them. Fewer eggs might not bring forth enough healthy birds.

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In **directional selection**, allele frequencies shift due to changing conditions in the environment.

The classic example is the Peppered moth in England. At one time, it was light-gray in color, and very uncommon to see a dark-gray moth. As industrialization grew, and the environment became polluted, the moths became dark!! They were now camouflaged and had a selective advantage. These dark moths survived and reproduced more, thus the allele frequencies of the population changed.

Insecticide resistance (**favorite DAT-type question**) is another fine example of directional selection.

Most... let's say 99% of the insects are killed off by the spraying of insecticide. 1% are able to survive. Perhaps some aspect of their genetic make-up or anatomy allows them to survive the deadly chemical. What do you expect to happen? When the next generation appears, there will be a significantly larger percentage that displays insecticide resistance.



This image is in the **public domain** because it contains materials that originally came from the Agricultural Research Service, the research agency of the United States Department of Agriculture

Disruptive Selection illustrates a very interesting phenomenon. Intermediate forms of a phenotype are selected against. Let us consider a small population of finches on the Galapagos Islands. The finches differ in beak size and shape. Longer beaks can open fruits and get to their seeds. Wider, but shorter beaks can simply crack the fruit on the ground and get to the seeds. The finches were studied during a drought. Survival was higher for those with long beaks and shorter but wider beaks than finches with intermediate beaks!

As you can see, individuals with either extreme variation of a trait have greater fitness than those that are average!!

To sum it up:

In an environment of black and white rocks and colored rabbits:

White rabbits... live... can hide against the white rocks

Chapter 44- Evolution and Populations

Black rabbits... live... can hide against the black rocks

Grey rabbits... die...

Clearly you see that as the number of favorable traits increase in individuals, the match between the specie and the environment improves. Adaptive evolution occurs.

Yes, genetic drift and gene flow can cause gene frequency to increase or decrease, as well as gene flow, but natural selection is the only evolutionary mechanism that will lead to adaptive evolution on a consistent basis.

What is sexual dimorphism?

Males and females are recognizably different in the way they look!! They could differ in:

- a) Size
- b) Color
- c) Behavior
- d) Outward appearance

For example:

Consider the Mandarin duck. The male has a red bill and colorful feathers, the female does not.



Male pheasants are large in size, have larger tails, and are colorful. The female has much less color, and smaller in size with a shorter tail.

Thus, this is a case of **sexual selection**. This is a “special case” of natural selection. Indeed so, sexual selection is often powerful enough that can lead to the death of the individual.

Color, for example, can indeed attract predators in addition to members of the opposite sex. However, the colorful animal often has a better time finding a mate.

Bottom Line: sexual selection often helps you find a mate to reproduce with, but does not provide any survival benefits!

Chapter 44- Evolution and Populations

Thus, hopefully you can see there are several ways selection can affect population variation:

- Stabilizing selection
- Directional selection
- Disruptive (Diversifying) selection
- Sexual Selection

There is indeed a tendency for directional and stabilizing selection to reduce variation. However, mechanisms do exist to counter it and allow genetic variation to continue.

A) Diploidy

Most eukaryotes are diploid, and much genetic variation lies hidden in the recessive allele. The recessive allele, that is harmful, for example, can remain hidden in the heterozygote individuals.

This heterozygote form actually “protects” the recessive alleles which could eventually bring new benefits if circumstances in the environment were to change.

B) Heterozygote advantage

Sometimes the “heterozygote advantage” is seen. Recall that a person heterozygous for sickle cell anemia is provided protection against malaria.

What is neutral variation?

Alleles that have a neutral impact on the fitness of an organism tend to accumulate in a population. These alleles are not removed by natural selection. These alleles may increase or decrease as a result of genetic drift.

Eye color is a fine example, as are variations in human fingerprints.

Hopefully you can see that a neutral mutation for example, are neither beneficial nor harmful to survival of an organism or its reproductive status.

Chapter 45- A Brief Look at Earth's History

A Brief Look at Earth's History

The Earth is approximately **4.5 billion years old**. Fossils have shown the changes on our planet over large time scales. This will illustrate what is called **macroevolution**.

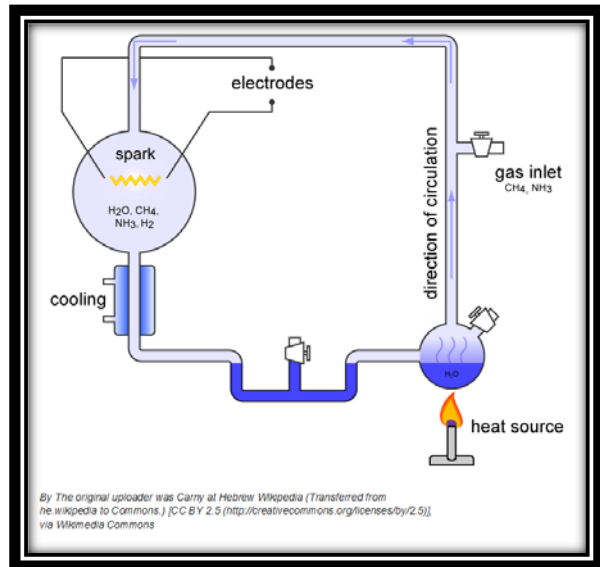
Early Earth had a reducing atmosphere **devoid of O₂**. Molecules such as CO₂, CH₄, NH₃, H₂S, H₂, were found. As Earth cooled, much of the H₂ escaped and H₂O vapor that was present condensed into oceans.



By NASA's Goddard Space Flight Center Conceptual Image Lab (Flickr) [CC BY 2.0
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Chapter 45- A Brief Look at Earth's History

Miller-Urey Experiment



Recall the famous **Miller-Urey experiment**.

They created laboratory conditions of the early Earth. In this experiment a mixture of H₂, NH₃, CH₄, and water were placed in a reactive chamber. A spark hit this mixture to simulate lightning. Within several days many amino acids and other organic compounds were formed.

For the DAT exam... the bottom line is this:

The Urey-Miller experiment showed that the abiotic (non-living) synthesis of organic molecules are possible.

Life needs two key properties:

- 1) Metabolism
- 2) Replication Mechanism

Obviously, to replicate DNA is needed. Many elaborate enzymes are needed, along with nucleotides to act as the building blocks. **The Urey-Miller experiment did not produce any nucleotides.**

Thus, I hope you can see why scientists still are baffled.

How did it all get here?

A theory evolved to present “molecule aggregates” called protobionts, evidently. (A word I always tell my students to be careful of- anytime a teacher or author says “evidently”... It really means “I haven’t a damn clue!”).

During the millions of years after the first rains began, organic compounds accumulated in a “soup”. Clay structures could have very well acted as templates by providing a surface for proteins to assemble. Clay surfaces likely allowed amino acids to join in less time and provided an “anchoring” surface.

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The protobionts formed appear to have had a membrane-like structure surrounding it. This membrane perhaps allowed for an internal environment to have been created.

Lab experiments have shown protobionts can spontaneously form from abiotically produced organic molecules.

e.g:

Lipids and Organic molecules  Liposomes

It turns out, these liposomes can form simple metabolic reactions. The liposome has an aqueous core surrounded by a hydrophobic membrane... in the form of a bilayer.

Bottom Line: Life is on its way to form!

Labs around the world have shown that RNA enzymes synthesized in the lab and were able to replicate!! No proteins or cellular components were necessary for this replication. Those self-replicating RNA enzyme systems do indeed share certain characteristics of life, they do not live as we know it. However, we are in the right direction.

The first genetic material was most likely RNA not DNA. These RNA enzymes are now called ribozymes. These ribozymes:

- a) Can catalyze specific biochemical reactions
- b) Can act in a similar fashion as protein enzymes

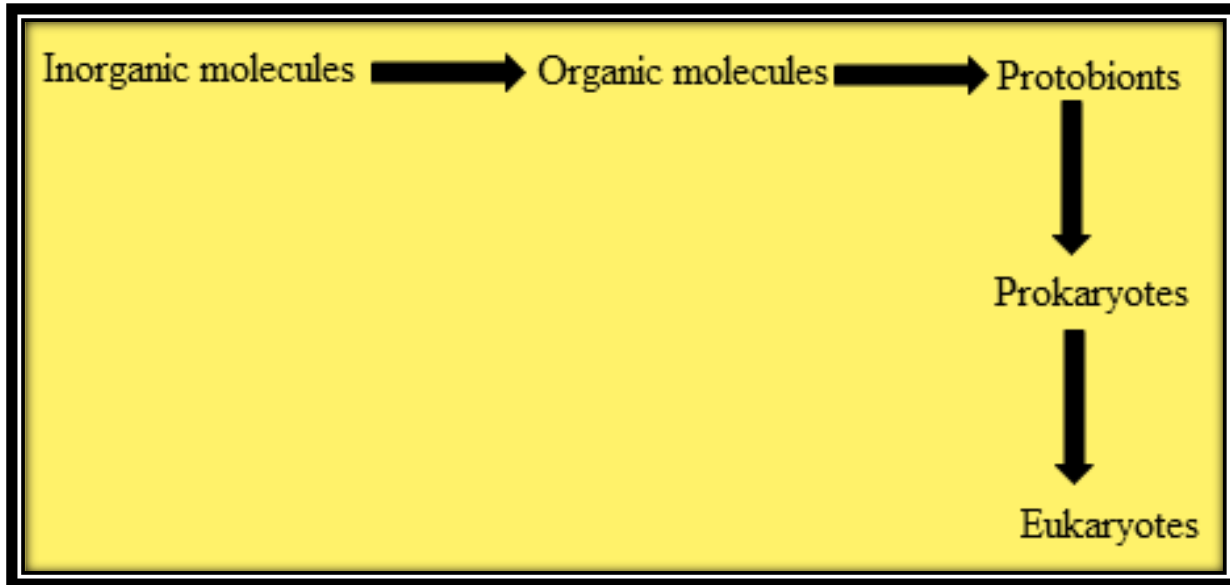
Ribozymes can indeed be produced in a lab. The 1982 discovery of ribozymes showed that RNA is both a genetic material as well as a biological catalyst. Clearly you see that most enzymes are proteins but not all!! Say hello to ribozymes.

By mechanisms not fully understood, RNA possibly allowed for the creation of DNA.

I invite you all to consult a biochemistry book on any theories on this. However, truth be known, we really are not sure exactly how DNA came on the scene.

To recap:

Chapter 45- A Brief Look at Earth's History



Fossil Record



The fossil record gives us much information about early life on Earth. It is based mainly on the sequence in which fossils have accumulated over the years in sedimentary rock layers (strata).

Is the fossil record biased?

100% yes!!! It only favors those species that lived for a long time and were abundant. Nevertheless, the fossil record still helps us learn of the biological changes that have occurred over such a great geologic time period.

Radiometric dating is based on decay of radioactive substances.

Chapter 45- A Brief Look at Earth's History



Let's do a quick **half-life** problem:

Carbon-14 has a half life of 5730 years. If we began with a 100 gram sample.

- a) How much is left after 22,920 years?

I always like to set up a table:

Time	Amount (in grams)
0	100
5730	50
11460	25
17190	12.5
22920	6.25

We have 6.25g left.

- b) How much has decayed?

$$100 - 6.25 = 93.75 \text{ g}$$

Chapter 45- A Brief Look at Earth's History

Geologic Record

What is a Geologic record?

This is the division of our planet's history into time periods. For example, there are three main eras:

- 1) **Cenozoic**- most recent. Age of mammals
- 2) **Mesozoic**- age of reptiles!!
- 3) **Paleozoic**- fish first appeared, land plants followed... animals moved to land too.

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
	Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic	2500
	Archean	Late Archean Middle Archean Early Archean	3800?
		Pre-Archean	

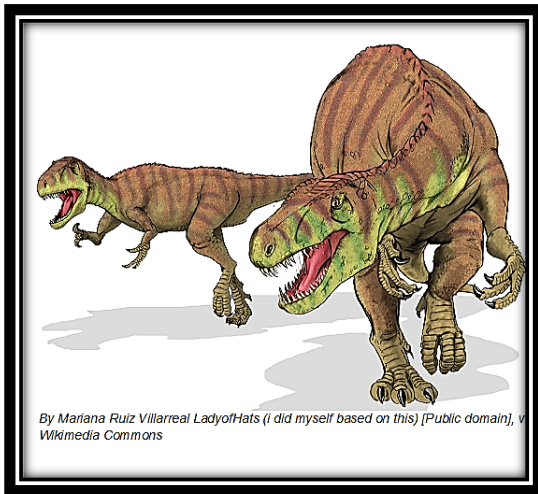
By United States Geological Survey (<http://pubs.usgs.gov/gip/fossils/fig15.gif>) [Public domain], via Wikimedia Commons

★ At the end of the Paleozoic era, the largest mass extinction in history wiped out almost 90% of all marine animal species. The reason why is highly debated.

Each era has been divided in a period. **The DAT will not get into much detail, but one period is important.** In the **Mesozoic Era**, we find the **Jurassic Period**. Just from the name... take a guess what animal was abundant!!!

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The **dinosaur** became the dominant terrestrial vertebrate early in the Jurassic Period occupying this position for about 135 million years.



The **Archaeopteryx** was long viewed as the earliest bird. Paleontologists now view it as a transitional organism that is intermediate between dinosaurs and birds. It is believed to have flown!! Archaeopteryx is however regarded as the oldest-known fossil animal.



How did dinosaurs become extinct?

There are a few theories, and I will present the most popular.

The **Asteroid Impact Hypothesis** concludes that a large asteroid hit the Earth. Dense dust clouds blocked the sun's rays which darkened and cooled the planet. Many plants died, and greenhouse gases created a very warm climate. This caused the dinosaurs to become extinct. Scientists have found a 150 km wide crater to help back up the theory.

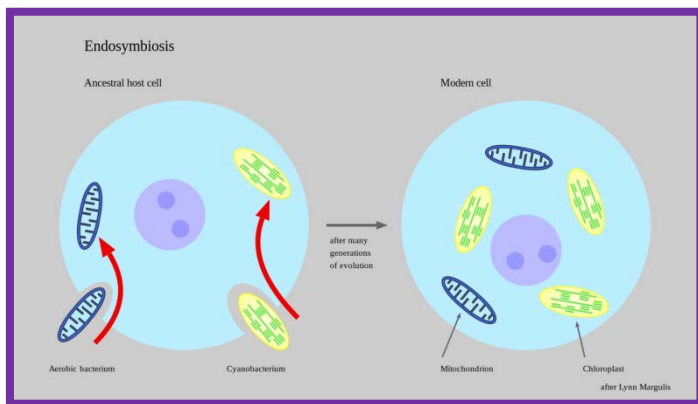
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Another piece of evidence comes from the high amount of an element called **Iridium, Ir**. Iridium is found in meteorites in much higher abundance than in the Earth's crust. The areas where the impact was believed to occur was high in Iridium. This does indeed suggest the impact of a massive extraterrestrial object.



Most of the O₂ came by way of **H₂O being split** during photosynthesis. Certainly, as O₂ levels began to rise, many prokaryotic organisms perished. O₂ can damage cells as well as inhibit many enzymes.

Endosymbiotic Hypothesis



Around **2.5 billion years ago**, the eukaryotic organisms appeared. (At least the oldest widely accepted fossils tell us this).

How did eukaryotes... which contain cell parts like nuclear membranes, lysosomes, mitochondria, endoplasmic reticulum, and other internal structures evolve from prokaryotes?

According to the **endosymbiotic hypothesis**, mitochondria and chloroplasts were formerly small prokaryotic organisms that began to live within larger cells!

A sure bet question for the DAT. Make sure that you are using the current year edition of DAT Destroyer, as I am always adding new problems to reflect what you are likely to see on your exam.

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The vast majority of biologists accept the endosymbiotic theory today as correct.

Bottom Line: Mitochondria and chloroplasts of today were the endosymbionts of yesterday.

For those with an interest in mass extinctions I have found the Campbell text an in-depth read and well written. I invite you to have a look. **If not, this should suffice for the DAT exam.**

Adaptive Radiations

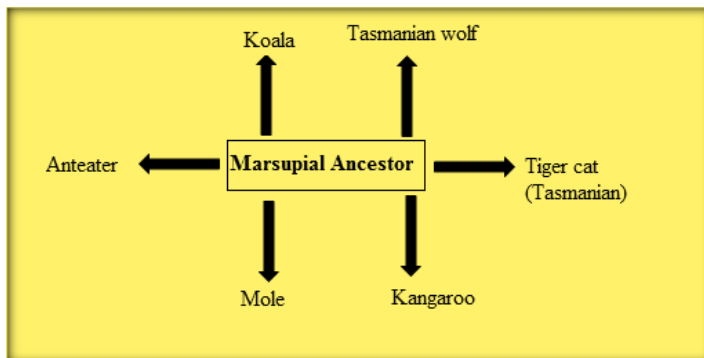
What is adaptive radiations?

This is a “burst of speciation” in which numerous species are produced from a common ancestor.

Adaptive radiations are common during the first few million years following a mass extinction.

e.g. the development of mammals occurred after dinosaur extinction.

e.g. The many finches seen today in the Galapagos Islands originated from a single ancestor, and the marsupials of Australia illustrate the adaptive radiation concept nicely.



★ Adaptive Radiation is a type of **Divergent evolution**. Adaptive radiations are not limited to only animals, but plants also have shown adaptive radiations. For example, in the Hawaii islands 28 species of a certain plant are known, but the entire family is traceable to a single ancestor. This is another example of an adaptive radiation.

Adaptive radiations, especially on islands that are remote from continents, have allowed, the successful “pioneers” to diversify into new niches without much competition, often becoming new species.

Major changes in the history of life have occurred. Continental drift, adaptive radiation, and, extinctions all played a role.

What is heterochrony?

This is a development change in the timing or rate of events leading to a change in size or shape. The speeding up or slowing down of growth appears to be a common occurrence seen in evolution.

Isometric vs. Allometric Growth

If all body parts grow at the same rate: isometric growth

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If body parts do not grow at the same rate: allometric growth

★ Human growth = allometric growth

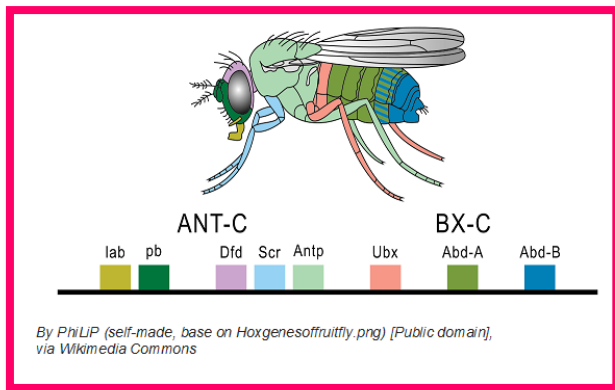
Your head takes up a larger % of your body when you were a baby than now as an adult!!

Changing facial features of a toddler would be another example of allometric growth.

This change in developmental timing can produce an organism that looks quite different from their ancestors, however the overall genetic change might be small.

As you can see, the point I am making is that genetic mechanisms of chance can also operate and change the organism's form. This can indeed be reflected in the fossil record.

Homeotic Genes



We can also see significant evolutionary changes which result from what is called homeotic genes. These genes control the placement and spatial organization of body parts. A homeotic gene might give the instruction as to where to place an arm or a leg in the developing organism.

Hox genes are one class of homeotic genes. A change in hox genes and in the genes that regulate them can have a huge effect on morphology, thus can contribute to evolutionary change. After the embryonic segments form, the Hox proteins determine the type of structure such as legs, wings, or antennae that will form on a segment.

Here is a cool example:

A mutation was induced in a homeotic gene of a Drosophila larvae. The mutant grows legs instead of antennae on its head!!

Homeotic genes are found in insects, mammals, echinoderms, and even plants!

Proteins are a product of gene expression, thus two organisms that have similar proteins usually have similar genes. This is often a valuable tool because if genes are similar we can see a possible link to a common ancestor.

Amino Acid Sequences are similar in proteins between common ancestors.